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Volume II. North Atlantic Treaty Organization/ Committee on the Challenges of Modern Society Papers

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16. ABSTRACT

This publication is one of three volumes that contain Japanese, American, and NATO papers presented at the Tenth United States/Japan Conference on Sewage Treatment Technology and the North Atlantic Treaty Organization/Committee on the Challenges of Modern Society (NATO/CCMS) Conference on Sewage Treatment Technology held in Cincinnati, Ohio, October 1985. The proceedings of the conferences comprise a useful body of knowledge on advances in sewage and wastewater treatment and sludge management technology. Subject matter covered includes municipal wastewater treatment including bioengineering applications and anaerobic treatment; sludge treatment and disposal including combustion, oxidation, composting, and toxics removal; odor control; small flow sewerage system; sludge conversion to oil, etc. Volume I, Part A, contains the Japanese Papers; Volume I, Part B, contains the American Papers; and Volume II contains the NATO Papers.

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OCTOBER 17-18, 1985

AND

NORTH ATLANTIC TREATY ORGANIZATION/COMMITTEE ON THE CHALLENGES OF MODERN SOCIETY (NATO/CCMS) CONFERENCE ON SEWAGE TREATMENT TECHNOLOGY

OCTOBER 15-16, 1985

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NORTH ATLANTIC TREATY ORGANIZATION/COMMITTEE ON THE CHALLENGES OF MODERN SOCIETY (NATO/CCMS) PAPERS

U.S. ENVIRONMENTAL PROTECTION AGENCY
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FOREWORD

The maintenance of clean water supplies and the management of municipal and industrial wastes are vital elements in the protection of the environment.

The participants in the Japan-United States-North Atlantic Treaty Organization/Committee on the Challenges of Modern Society (NATO/CCMS) Conferences on Sewage Treatment Technology completed their conferences in Cincinnati, Ohio, in October 1985. Scientists and engineers of the participating countries were given the opportunity to study and compare the latest practices and developments in Canada, Italy, Japan, The Netherlands, Norway, the United Kingdom and the United States. The proceedings of the conferences comprise a useful body of knowledge on sewage treatment which will be available not only to Japan and the NATO/CCMS countries but also to all nations of the world who desire it.

Lee M Thomas

Lee M. Thomas
Administrator

Washington, D.C.

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NORTH ATLANTIC TREATY ORGANIZATION/
COMMITTEE ON THE CHALLENGES OF MODERN SOCIETY
CONFERENCE ON SEWAGE TREATMENT TECHNOLOGY

CINCINNATI, OHIO
OCTOBER 15-16, 1985

A Committee on Advanced Wastewater Treatment of the North Atlantic Treaty Organization/Committee on the Challenges of Modern Society (NATO/CCMS) held a conference on sewage treatment technology in Cincinnati, Ohio, on October 15-16, 1985. The NATO/CCMS Committee on Advanced Wastewater Treatment, chaired by Dr. J. Duane Salloum of Canada, included delegates from six NATO countries: Canada, Italy, the Netherlands, Norway, the United Kingdom and the United States.

The conference on sewage treatment technology featured National papers on advances in wastewater treatment and sludge management technology in the participating NATO countries. Highlights of the conference included:

- A Canadian report on improved control of sludge dewatering and on conversion of sludge to oil;
- Italian advances on control of toxic metals and innovative anaerobic treatment of wastewaters;
- Dutch studies on toxics removal and disposal of sludges;
- Norwegian advances in sludge management, nutrient control and septage handling;
- British advances in sludge digestion and improved management of wastewater treatment plants; and
- American advances in wastewater treatment and sludge management related to control of pathogens and toxics.

CANADIAN ADVANCES IN SLUDGE MANAGEMENT TECHNOLOGY

by

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North Atlantic Treaty Organization/Committee on the Challenges of Modern Society (NATO/CCMS) Conference on Sewage Treatment Technology

October 15-16, 1985
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ABSTRACT

Two new approaches to sludge management in the sewage treatment industry have been developed over the past few years. A new concept in automated control of the conditioning and dewatering of sludge using rheology as the control approach optimized the dewaterability of sludge while minimizing the cost of polymer addition. The control strategy used a computer algorithm which correlates the rheological properties of the sludge measured by a viscometer with polymer demand. The viscometer and polymer feed pump, interfaced to the computer, were successfully used by the control algorithm to automatically adjust the polymer flow rate. In a second approach, the conversion to sludge to oil has been developed at batch and continuous pilot scale as an attractive alternative to the sludge disposal options currently in operation. The conversion process, at 300 to 500°C heating dried sludge in a nitrogen atmosphere, successfully produced oil and char from sludge. The process was stable with typical oil yields of 25.4 percent, char yields of 61.1 percent and non-condensable gas of 11.1 percent. The oil viscosity under optimum operating conditions was 33.7 centistokes.

INTRODUCTION

Sewage sludge is an unavoidable by-product of wastewater treatment and roughly one tonne of sludge is generated per 4,540 m^3 (1.0 million gallons) of wastewater treated (1). Disposal of sewage sludge is an expensive process and normally constitutes up to 50% of the total annual costs for wastewater treatment. It is estimated that over 500,000 tonnes of dry sewage sludge are produced annually in Canada and disposed of at a total cost of about $104 million (2). Major sludge disposal options used in Canada include agricultural utilization, landfilling and incineration, with estimated disposal costs ranging from about $126/tonne for agricultural utilization to over $300/tonne for incineration (3).

The problems of sludge disposal are expected to intensify in the future due to a number of factors. The total cost of sludge disposal will increase as the quantity of sludge to be disposed of, increases. The fraction of sludge disposed of by agricultural utilization will probably decrease due to the problem of finding suitable land within a reasonable distance of large population centres. Potential restrictions on the loading rates for sludges with high levels of heavy metals may also contribute to a decline in this practice. The feasibility of landfilling will decrease as public opposition to the licensing of new disposal sites continues to grow.

It would appear that the immediate future in sludge disposal technology will feature a trend towards more complex systems, which also implies higher costs. This will be especially true for the large urban areas where the impact of the above factors will be most keenly felt. In order to control costs, alternative resource recovery oriented solutions based on either the upgrading of current technology or the implementation of new technology, are needed.

TECHNOLOGY REVIEW

Upgrading current technology has been primarily concerned with improvements in dewatering and incineration. The trend has been towards considering sludge treatment from an overall systems design approach. The incentive for upgrading has been provided by the large increases in energy costs over the last ten years, and the realization of how energy inefficient most incinerator installations were. In 1973 when natural gas cost 3.6 cents/m^3, it was economically justifiable to incinerate sludge cakes of only 15 to 18% total solids. Today, natural gas costs are in the order of 18 cents/m^3, and more cost-effective methods of accomplishing moisture removal must be implemented.

Modifications which have been designed to either increase cake solids or improve the amount of energy recovered from an incinerator system include the following:

1. Upgrading from vacuum filters to belt or membrane presses.
2. The use of incinerator off-gases to dry a portion of the sludge stream.
3. Modification of incinerator burners to use digester gas as fuel.
4. Modifications to multiple-hearth incinerators to allow very dry cakes to be introduced on an intermediate hearth.
5. Waste heat recovery to generate steam, which can in turn be used to drive other processes such as thermal conditioning.

In Canada, the improvements described above are either still in the design and construction phase or have only been in operation for a relatively short period of time. Consequently, reliable information is not yet available with respect to the cost of the modifications or their effect on the energy balance of the system.

Another approach to offset costs is the introduction of process control to make treatment systems more efficient. This is being investigated for the treatment of the liquid train in areas such as dissolved oxygen control in aeration basins, control of sludge inventories and the control of pumps in lift stations, and shows promise of realizing substantial savings. With the large expenditures being committed to sludge processing it seems reasonable to assume that comparable savings could be achieved by the implementation of process control. One of the major drawbacks to this has been the lack of sensors capable of measuring sludge characteristics and consequently most attempts have had to rely on indirect measurements. Knudsen and Mathes (4) evaluated a strategy to control chemical conditioning, vacuum filtration and multiple-hearth incineration. Indirect measurements had to be used because sensors for the on-line measurement of sludge dewaterability, cake moisture and sludge calorific value were not available. Under these circumstances, they were still able to show a saving of approximately 26% in chemical conditioning costs.

Alternative technologies also offer the potential for improved energy recovery and decreased cost.One of the most advanced is the Hyperion Energy Recovery System currently being installed in Los Angeles (5). This system comprises digestion, dewatering, Carver-Greenfield dehydration and starved air fluid bed incineration of the sludge derived fuel. It is estimated that processing 366 tonnes of raw sludge per day will generate a total of 25 MW of electricity, with 10 MW available for sale back to the local utility. The complete plant is expected to be in operation by late 1985.

Sludge liquefaction has been reported as a viable method for energy production from sewage sludge, but the technology is still in its infancy. Researchers from Battelle Northwest Laboratories have reported on a sophisticated process consisting of sludge alkaline pretreatment and subsequent autoclaving at 320°C for one hour at 10,000 kPa under an Argon atmosphere (6). This process produces oil, asphalt and char, with oil yields ranging up to 15% (on a total sludge solids basis). The technology is currently being evaluated at pilot scale.

The basic concept of low temperature pyrolysis of sewage sludge to produce fuel products has been known for many years (7). Recently, German researchers have made significant advances in understanding the mechanisms by which sludge is converted to oil (8). They heated dried sludge to 300-350°C in an oxygen free environment for about 30 minutes. The researchers postulated that catalysed vapour phase reactions converted the organics to straight chain hydrocarbons, much like those present in crude oil. Analysis of the product confirmed that aliphatic hydrocarbons were produced, in contrast to all other processes which produce aromatic and cyclic compounds, whether utilizing sludge, cellulose or refuse as the substrate. The German researchers have demonstrated oil yields ranging from 18-27% and char yields from 50-60%. The oil had a heating value of approximately 39 MJ/kg and the char about 15 MJ/kg.

Environment Canada's Wastewater Technology Centre is currently developing two processes which involve both approaches to upgrading sludge management practices. The first process which will be discussed is an example of upgrading existing technology and consists of developing a method for the automatic control of polymer addition for sludge conditioning. This work is based on the concept that measured rheological properties can be used to predict the dewaterability of a sludge. The second process is the conversion of sludge to solid and liquid fuels, and is an example of alternative new technology. The conversion process under evaluation is carried out at low temperature and atmospheric pressure.

AUTOMATIC POLYMER CONTROL

BACKGROUND

Rheology can be defined as the study of the properties and behaviour of matter in the fluid state. Most single-phase fluids exhibit Newtonian behaviour in that the rate of viscous flow is proportional to the shear stress. The addition of solid particles to the fluid interferes with the free flow of the dispersion medium to a degree that is dependent on the rate of shear. Dispersed systems such as these can exhibit a variety of rheological behaviours including plastic, pseudoplastic and altered Newtonian. Most sewage sludges have been interpreted as exhibiting either plastic or pseudoplastic flow (9). They may or may not possess an initial characteristic yield stress depending on the shape of the flow curve and the definition of yield stress.

The rheology of sewage sludge is further complicated by the fact that most sludges are also thixotropic, meaning they possess an internal structure which breaks down as a function of time and shear rate. A flow curve or rheogram (Figure 1) of a typical sludge, showing the curves produced by a rotating viscometer during the increasing and decreasing rate of shear cycles, indicates that the rheology of the sludge has been altered during the initial (increasing) phase of the test. The displacement of the two curves is referred to as a hysteresis loop and is a measure of the degree of thixotropy exhibited by the sludge.

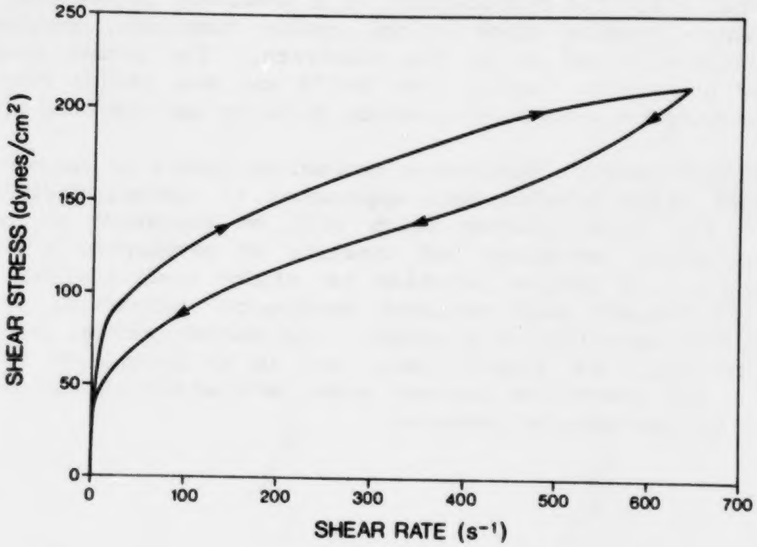


Figure 1. Typical rheogram illustrating thixotropy.

The concept of using rheology as a control measure arose out of a sludge characterization study conducted at the Wastewater Technology Centre (WTC) (10). The general relationship between sludge rheology and polymer addition shown in Figure 2 was consistent for all sludges tested and resulted in two important observations. Firstly, the initial shear stress or yield stress was observed to increase as the polymer dosage increased. Secondly, the polymer dosage (6 kg/t) which resulted in an initial peak or point of inflection in the rheogram compared favourably with that dosage which produced efficient performance during concurrent pilot-scale dewatering trials. The fundamental assumption which prompted evaluation of rheology as a means of control was that optimum conditioning of the sludge would be achieved when a peak became evident in the rheogram.

The use of rheology as a basic parameter required that a standardized laboratory methodology be developed (11). This included both the method of adding the polymer and the method of operating the viscometer. The method selected for adding chemicals (polymers) to the sludge, consisted of adding the required volume of polymer over a 10-second period, while mixing the sludge at 1000 rpm by a standard stirrer developed by the Water Research

Centre (12). A Haake Rotovisco RV3 rotational viscometer with a MVII sensor system (gap width = 2.5 mm) was used for all rheological measurements. The acceleration rate was standardized at 75 rpm/min and the damping option was not utilized.

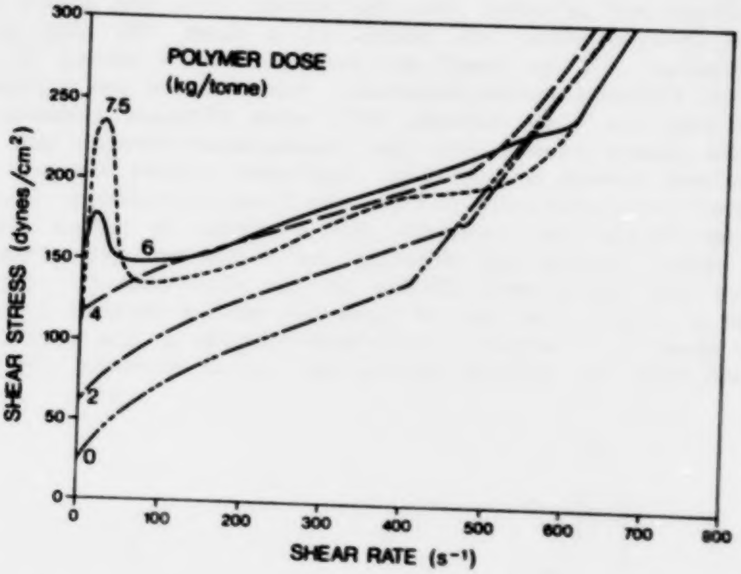


Figure 2. Rheograms of polymer conditioned sludge.

The second phase of the study (13) demonstrated the sensitivity of rheograms to changes in sludge dewaterability and solids concentration. During this phase the viscometer equipment was upgraded to a Haake RV-100 and was interfaced to a real-time computer. Experiments were conducted using sludge conditioned in batch samples and analyzed in the batch mode on the viscometer. The results indicated that rheological measurements were sufficiently sensitive to quantitatively identify differences between sludges, the effect of polymer addition, the effect of changes in sludge solids concentration and the effects of changes in dewaterability induced by detergent addition.

PILOT-SCALE CONDITIONING SYSTEM

The most recent stage of the program involved the development of a continuous-flow, pilot-scale sludge conditioning system, the modification of the viscometer to function on-line and the development of a preliminary control strategy.

A schematic drawing of the pilot-scale conditioning set-up is shown in Figure 3. The sludge storage tank was capable of holding approximately 1200 L of sludge and was equipped with a variable speed mixer to prevent sedimentation. The sludge pump was a variable speed positive displacement Moyno pump with a range of 0.05 to 0.37 L/s. Solids concentration was varied by the addition of dilution water to the suction side of the sludge pump. Cationic polymer was injected into the sludge line just prior to the in-line mixer. The in-line mixer was housed in a clear PVC pipe section (47 mm internal diameter, 470 mm long) and consisted of a series of six stainless steel, helical elements welded together. Each element was approximately 75 mm long and rotated the flow through 180°, with adjacent elements being offset by 90°. The sludge flowed into the flocculator through the bottom of the tank and drained through an overflow. Although a mixer was provided to ensure good mixing of the conditioned sludge, the final methodology involved shutting off the mixer during the viscometer run in order to reduce turbulence. The viscometer sensor system was attached to a bracket such that it could be lowered into the conditioned sludge in the flocculator. Experiments were conducted at a sludge flow rate of 0.08 L/s with a nominal retention time in the in-line mixer of 9 seconds. The concentration of the polymer solution was adjusted such that the polymer dosing rate never exceeded 10% of the sludge flow rate.

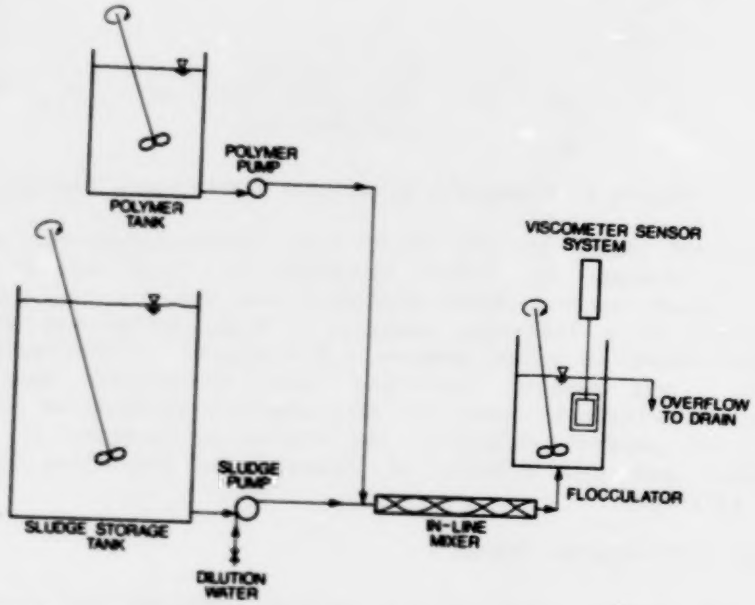


Figure 3. Pilot-scale, continuous-flow, sludge conditioning system.

The viscometer sensor system had to be modified to allow measurements to be taken in an open vessel. The sensor system selected was comparable to that used in the batch experiments, in that it was an integral cup and rotor system. The differences were that the gap was marginally wider (2.6 mm as compared to 2.5 mm), the geometry was slightly different (length and diameter), and the cup had four slots in the wall and several holes in the bottom. The batch sensor was operated by putting the sample in the cup and then inserting the rotor. In the pilot-scale sensor system the cup and rotor were assembled as a unit attached to the motor drive. The cup/rotor portion was immersed in an open container of sludge where the sludge flowed through the slots and holes in the cup, and filled the annular space between the cup and the rotor. Additional modifications included enlarging the holes in the bottom of the sensor cup and placing an inverted plastic container over the cup/rotor assembly such that the bottom was completely open and there was an annular ring around the sensor approximately 30 mm wide. These changes facilitated the flow of sludge into the area between the cup and the rotor, particularly when the sludge was highly flocculated.

The rheograms shown in figures 4, 5 and 6 were generated with the pilot-scale sludge conditioning system and represent typical curves. The general relationships were valid for all sludges tested. Although some noise was apparent in the curves these rheograms have been drawn as smooth curves to facilitate interpretation when there are several curves on one figure. Capillary suction time (CST) was also used to measure the dewaterability of the conditioned sludge and is shown in the figures.

Figure 4 shows the effect of polymer dosage on rheology when the sludge is conditioned on a continuous basis. Since all of the experiments were conducted with the intent of eventually applying the results to the operation of a belt filter press, it was accepted that the sludge would have to be highly flocculated. This condition is normally satisfied with a CST < 20 seconds. Reference to Figure 4 shows that the shear stress at low shear rates ($<10s^{-1}$) increases as the polymer dosage increases. The limiting condition of CST = 20 seconds is achieved at a polymer dosage of 3.5 kg/t and a

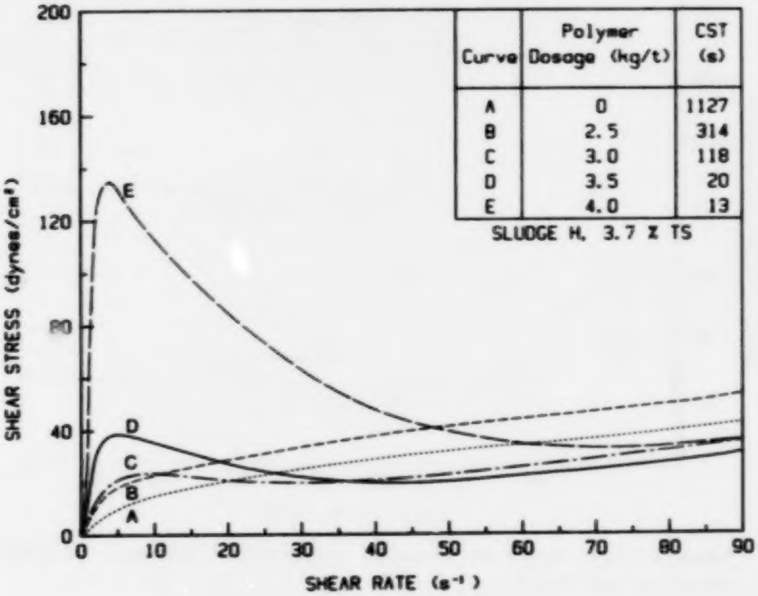
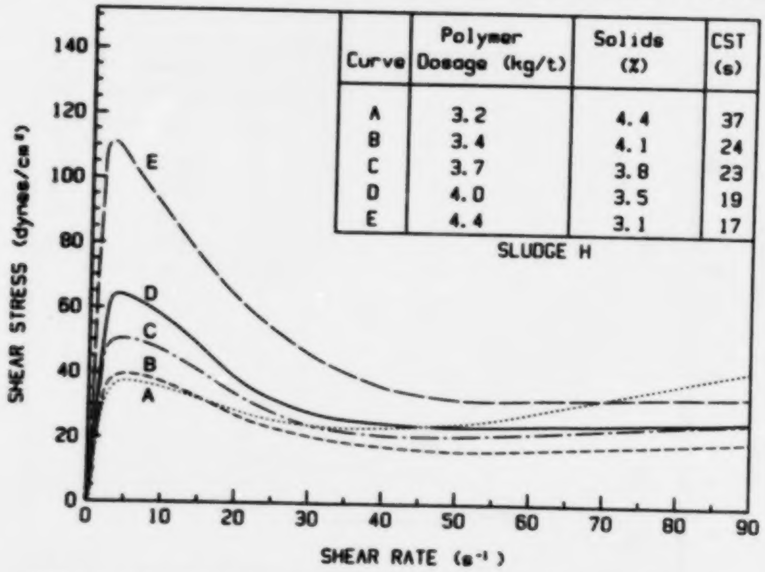


Figure 4. Effect of polymer dosage on rheology.

significant peak is evident in the rheogram. The trends shown are similar to those observed with the batch system but the curves have a slightly different shape. The continuous-scale curves rise very rapidly to a peak and then decay, resulting in curves which are more definitely skewed to the right than those generated on the batch system. This effect is attributed to the differences between the geometries of the batch and continuous systems.

Another difference is also evident. With the batch system it was assumed that a peak in the rheogram, i.e., a point of inflection with zero slope, was sufficient to ensure optimum conditioning. This is no longer completely true with the continuous system. Curve C in Figure 4 very definitely has an area of zero slope at approximately 10 s^{-1} but the corresponding CST of 118 seconds indicates that the sludge is not optimally conditioned. The situation is such that while the existence of a peak in the rheogram is still a necessary condition for optimal conditioning, it does not represent adequate flocculation as measured by the CST test.

Figure 5 shows the effect of varying the solids concentration when the polymer flow rate is not adjusted accordingly. In this test the solids concentration was altered by adding dilution water but the total sludge flow rate (including dilution water) and the polymer volumetric flow rate were kept constant. Under these conditions, as the solids concentration decreases, the polymer dosage on a unit basis (kg/t) increases. At the highest solids concentration (4.4%) the effective polymer dosage is 3.2 kg/t and results in a CST of 37 seconds. At this CST the sludge would not be considered to be super flocculated, and while a peak is present in the rheogram, it is not substantial. As the solids concentration decreases to 3.1% the effective



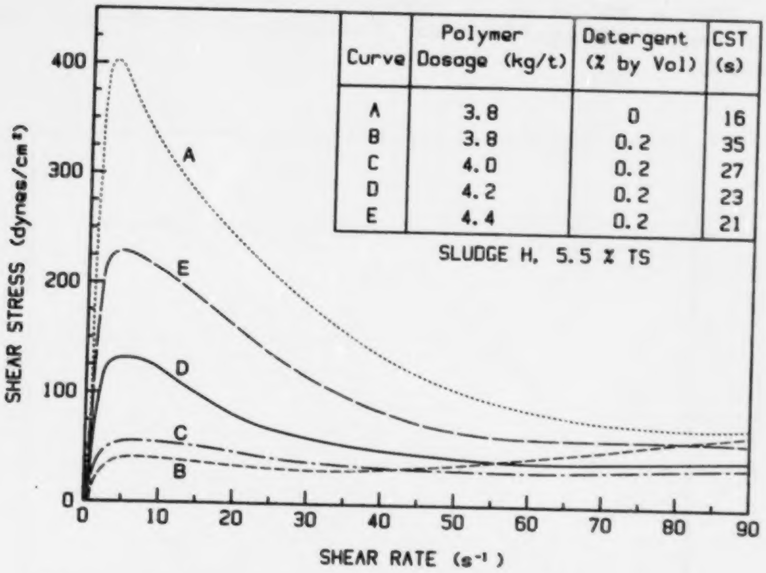
Curve	Polymer Dosage (kg/t)	Solids (%)	CST (s)
A	3.2	4.4	37
B	3.4	4.1	24
C	3.7	3.8	23
D	4.0	3.5	19
E	4.4	3.1	17

SLUDGE H

Figure 5. Interaction between solids concentration and polymer dosage with respect to rheology.

polymer dosage increases to 4.4 kg/t, the CST decreases to 17 seconds, and the rheogram peak becomes quite pronounced. The situation has changed from one where the polymer dosage is less than optimum to one where polymer overdosing may be occurring.

The results in Figure 6 show the effect of detergent addition on sludge conditioning and the resulting rheograms. Detergent, a deflocculant, was used to artifically alter the dewatering characteristics and polymer demand of a sludge without changing the solids concentration. Curve A, with a significant peak and a CST of 16 seconds represents a well conditioned sludge. Curve B, at the same polymer dosage but with the addition of 0.2% by volume of detergent has the appearance of an unconditioned sludge in terms of both rheogram peak and CST. As polymer addition increases, under a constant detergent addition, the polymer (Curves C through E) overcomes the effect of the detergent until at Curve E, the situation is very similar to that of Curve A. The notable exception is that 4.4 kg/t of polymer is required for Curve E as compared to 3.8 kg/t for Curve A. This is analagous to what happens in actual operation. As the dewaterability of a sludge changes, usually for unknown reasons, the polymer dosage must vary accordingly in order to maintain the same level of performance.



Curve	Polymer Dosage (kg/t)	Detergent (% by Vol)	CST (s)
A	3.8	0	16
B	3.8	0.2	35
C	4.0	0.2	27
D	4.2	0.2	23
E	4.4	0.2	21

Figure 6. Effect of detergent addition on rheology.

DEVELOPMENT OF CONTROL STRATEGY

A control strategy for sludge conditioning must satisfy the following three criteria:

1. optimize dewaterability of the sludge,
2. minimize cost of polymer addition,

3. respond to changes in sludge properties by altering polymer dosage.

The control strategy developed at the Wastewater Technology Centre utilized a HP87/HP1000 computer combination and the pilot-scale conditioning system shown in Figure 3. A preliminary algorithm was developed which correlated the rheological properties measured by the viscometer, with polymer demand. The viscometer and polymer feed pump were interfaced to the computer, such that data from the viscometer run was used by the control algorithm to automatically adjust the polymer flow rate. A tentative optimum polymer dosage was identified on the basis of CST (i.e., <20 seconds) and the particular rheogram corresponding to that polymer dosage selected as a reference rheogram. Specific characteristics of the reference rheogram were stored in the computer memory and used as the control setpoints.

Figure 7 shows one of the preliminary attempts to automatically control polymer dosage. It had been determined that the optimum polymer dosage for the sludge was approximately 4 kg/t. The test run was initiated at a dosage of 0.5 kg/t and the control system allowed to determine the optimum. Viscometer tests were conducted at 8 minute intervals. Based on this input to the control algorithm, polymer dosage was increased from the initial 0.5 kg/t to 4.0 kg/t over a period of 70 minutes. Although the control is somewhat crude due to the necessity of manual sampling, it is obvious that the basic concept is valid.

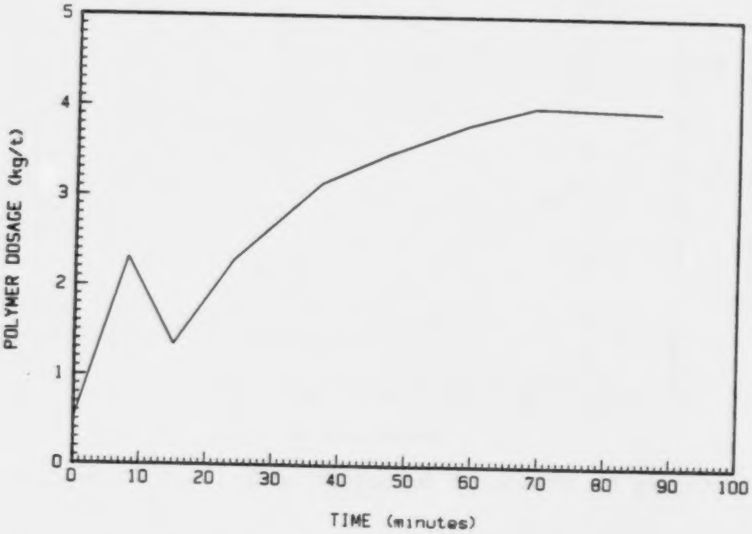


Figure 7. Effect of automatic control on polymer dosage.

DEMONSTRATION

The final stage of the study, which is currently underway, involves demonstration of the control package at full-scale. The general layout is shown schematically in Figure 8 and utilizes a 0.5 m Komline-Sanderson belt filter press. Both the dilution water/detergent and polymer pumps are interfaced with the computer. Temporal variations in feed sludge characteristics are generated by programming the operation of the dilution water/detergent pumps. Samples of the conditioned sludge are withdrawn to the sample vessel at discrete intervals. Viscometer tests are initiated automatically by the computer and data input to the control algorithm. The computer will then initiate the appropriate control action with respect to the polymer pump.

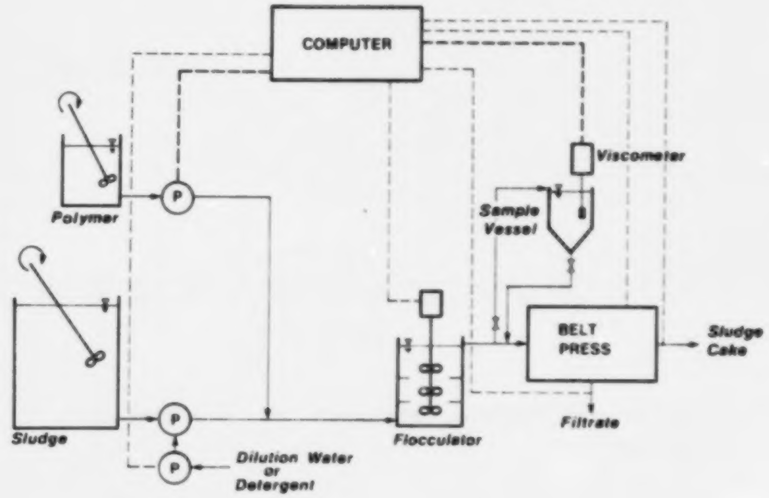


Figure 8. Control strategy for full-scale sludge conditioning/dewatering.

The results in Figure 9 illustrate the response of the control system to changes in the concentration of the feed sludge. During the initial 60 minutes the dewatering system was coming to equilibrium. During the steady-state period (as defined by consistent belt press performance) from 60 to 200 minutes, the average polymer flow rate was 4.54 L/min. The break in the data from 200 to 270 minutes resulted from some pluggage in the feed lines, but when this had been rectified and the solids concentration of the sludge decreased from 4.6 to 4.2 %, the resulting average polymer dosage had also decreased. The decrease in polymer flow rate from 4.54 to 3.69 L/min represents a polymer saving of approximately 20 % whereas the decrease in solids was only about 10%.

In Figure 10 the effect of altering the dewaterability of a sludge by the addition of detergent is shown. The polymer dose during the first steady-state period was 4.45 L/min. At approximately 105 minutes a small percentage (0.15% by volume) of detergent was added to the incoming sludge. The control system sensed that the polymer requirement had changed and proceeded to adjust the polymer pump accordingly. The average flow rate required during the period of detergent addition was 5.51 L/min, or an increase of approximately 24%. When the addition of detergent was terminated, the polymer flow rate returned to the same general level as before the addition.

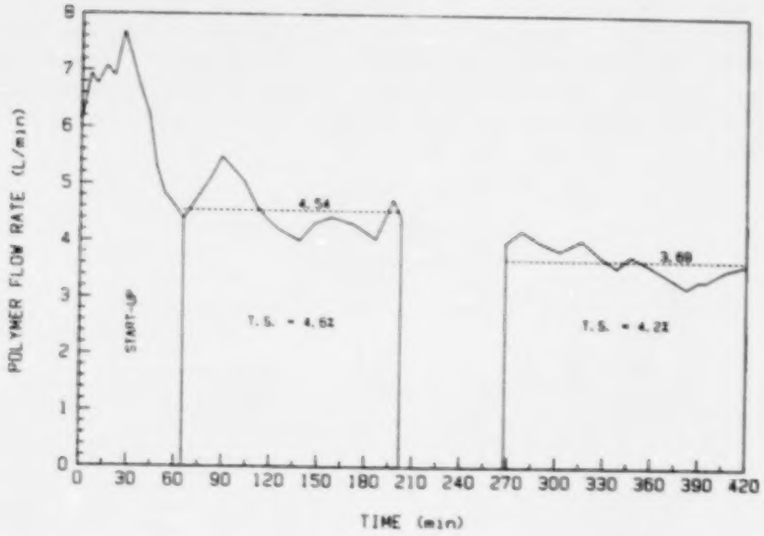


Figure 9. Response of control strategy to fluctuations in sludge solids concentration.

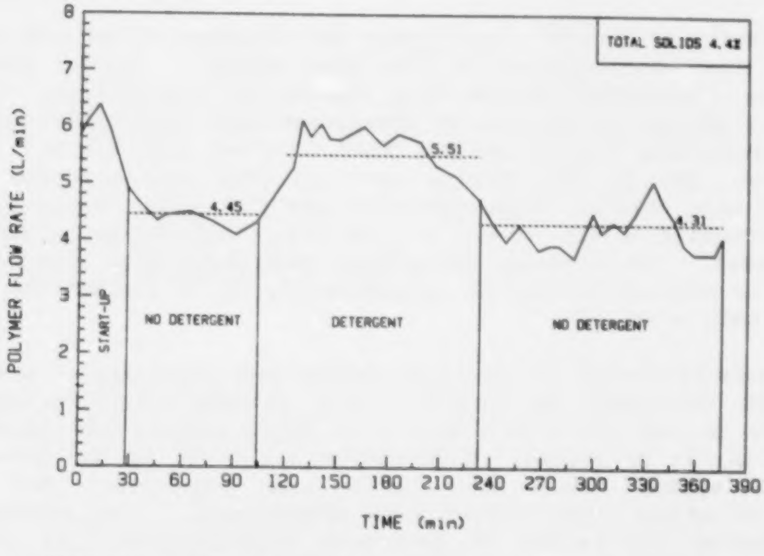


Figure 10. Response of control strategy to fluctuations in sludge dewaterability.

The preliminary results from the demonstration phase have shown that the control system is sensitive to gross changes in sludge dewaterability, whether these are the result of changing solids concentration or the presence of materials which act as deflocculants. The net impact on cost will depend upon what degree of fluctuation in sludge dewaterability is observed when the system is field tested. The projected benefits of an automatic control system include reduced polymer cost, decreased product variability and reduced process costs downstream.

CONVERSION OF SLUDGE TO LIQUID AND SOLID FUELS

The Wastewater Technology Centre's evaluation of low temperature conversion of sewage sludge to fuel, an example of an alternative new technology, was designed as a three phase program. The first phase involved testing a number of sludges using a batch apparatus. The second phase consisted of designing, constructing and testing a 1 kg/h continuous-flow reactor. The primary purpose of the second phase was to generate process design information and cost data, in order to assess the potential of the technology at full scale. The final phase of the program will be demonstration of the technology at full scale.

BENCH-SCALE STUDIES

Methodology

Raw sludges containing a mixture of primary and waste activated sludge (WAS) from three different sewage treatment plants in Ontario were evaluated during this study. All sludges were oven dried (70°C) to about 90-95% solids. Analyses of these sludges indicated they were similar in composition with volatile solids of 55-64%, calorific values of 15-18 MJ/kg and carbon contents of 24-36%.

The bench-scale studies were carried out using a batch reactor and a continuous flow system. The batch reactor, a pyrex tube 70mm in diameter and 720 mm in length, was heated in a three-zone Lindberg furnace under a nitrogen atmosphere (Figure 11). Off-gases were condensed in a trapping system using ice as the coolant. Non-condensable gases (NCG) were vented from the system. A run was conducted by charging 550 g of dried sludge into the reactor and deaerating with nitrogen. Once operating temperature had been reached, the nitrogen purge rate was reduced. When all visible signs of reaction (i.e., gas/oil flow) ceased, the heat was switched off and the nitrogen purge rate was increased for approximately 30 minutes. The system was dismantled and the char, oil and reaction water collected and stored for analysis. Oil/water separation was achieved using a separatory funnel.

A photograph of the continuous reactor system is shown in Figure 12. It comprises a stainless steel shell, 50 mm internal diameter by 1000 mm long, fitted with a sludge/char conveying system and is heated using the same furnace as for the batch reactor system. The reactor is subdivided by a helical gas seal, into a volatilization zone and a char/gas contact zone. The

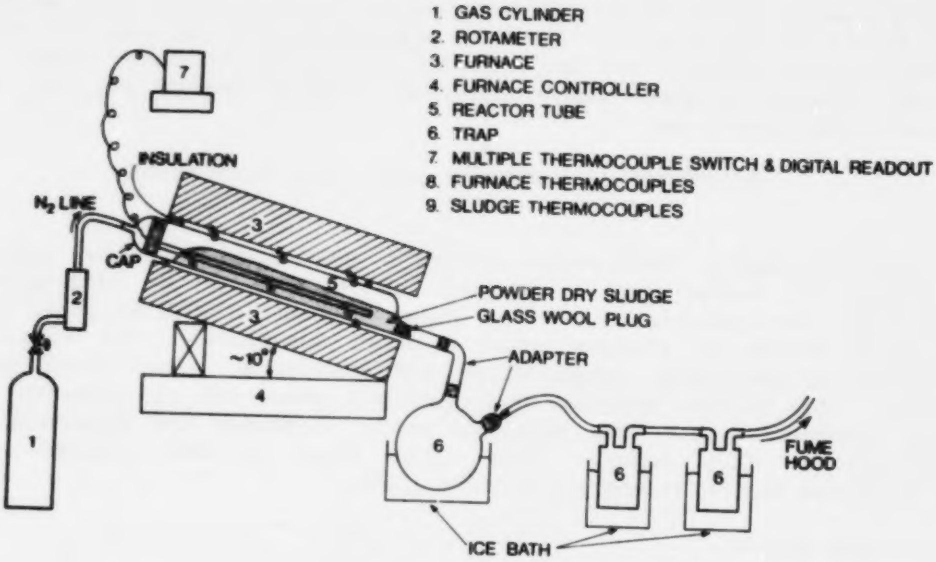

1. GAS CYLINDER
2. ROTAMETER
3. FURNACE
4. FURNACE CONTROLLER
5. REACTOR TUBE
6. TRAP
7. MULTIPLE THERMOCOUPLE SWITCH & DIGITAL READOUT
8. FURNACE THERMOCOUPLES
9. SLUDGE THERMOCOUPLES
INSULATION
N_2 LINE
CAP
POWDER DRY SLUDGE
GLASS WOOL PLUG
ADAPTER
~10°
FUME HOOD
ICE BATH
1
2
3
3
4
5
6
6
6
7

Figure 11. Batch experimental equipment.

Figure 12. Continuous reactor system.

reactor system is designed for dry sludge feed rates of up to 1 kg/h. Solids retention time in the reactor is controlled by varying both the sludge feed rate and reactor inventory. Sludge is fed to the reactor by a calibrated screw conveyor and travels through the reactor by means of the reactor conveyor. Volatilized material is withdrawn in the first zone and can be contacted with the char in both co-current and counter-current modes in the second stage. Product vapours are condensed externally as per the batch reactor system. Inert gas is used to purge the system of oxygen and the operating pressure is generally less than 2 000 pascals. Prior to collection of experimental data the system was allowed to reach thermal and chemical equilibrium by operating for at least three solid retention times (SRT).

Results

The results achieved with both the batch and continuous reactor systems are presented in detail in other publications (14,15). A summary of typical results are presented in Table 1. All the data is expressed on a dry solids basis (corrected for the normal 4-7% moisture present in the sludge) and the calorific values are expressed on a total solids basis (not corrected for volatiles).

TABLE 1. TYPICAL OPERATING CONDITIONS AND RESULTS

	Batch	Continuous
Feed Rate (g/h)	NA	750
Temperature (^{o}C)	450	450
OIL		
Yield (%)	22.3	25.4
Viscosity (cstks)	>214	33.7
Calorific Value (MJ/kg)	38.9	36.7
CHAR		
Yield (%)	54.6	61.1
Calorific Value (MJ/kg)	9.4	6.2
NCG		
Yield (%)	12.1	11.1
Calorific Value (MJ/kg)	NM	5.8
REACTION WATER		
Yield (%)	11.0	5.0

NA=Not Applicable
NM=Not Measured

In general, the results from the batch and continuous systems are quite comparable. The oil and char yields are slightly higher from the continous unit but it is difficult to say whether the difference is statistically significant. The lower calorific value of the char from the continuous reactor is the result of the lower carbon content. The most obvious difference between the products from the two systems is the oil viscosity. The oil from the batch runs was solid at room temperature (>214 centistokes), while the oil from the continuous runs was fluid at room temperature (33.7 centistokes). The batch system generated approximately twice the amount of reaction water as did the continuous one.

Although most observations are valid for either batch or continuous results, the following discussion will be limited to only the continuous system due to the fact that the experimental data base is much larger.

The yield of individual products and the split between products is a function of operating temperature. At low temperatures, the product split tends towards the formation of char. As the temperature increases to the optimum, the oil yield increases (8 to 25%) while the char yield decreases (75 to 61%). Above the optimum temperature the oil yield begins to decrease as conditions favour the formation of increasing quantities of non-condensable gas. Oil yield appears to be related to solids residence time but since it is impossible to completely separate the effects of SRT and char inventory, the trends are not clear. The yield of reaction water does not appear to be directly related to the operating parameters of the system. The yields of both oil and char are very much a function of the specific sludge used as the feed material.

The calorific value of the oil appears to be related to both SRT and temperature but their effects are relatively small. A range of SRT's from 10 to 24 minutes resulted in calorific values from 36 to 37 MJ/kg, while temperature variations from 300 to 500°C resulted in a range of only 36 to 39 MJ/kg. The calorific value of the char tends to decrease with increasing temperature but is relatively insensitive to changes in SRT. The magnitude of change in the energy of the char (i.e., from 10.4 to 5.5 MJ/kg), is substantially greater than that of the oil. The calorific value of the non-condensable gas increases in direct proportion to the temperature. This is due to the increase in the percentages of hydrogen, methane and ethane produced at higher temperatures.

The viscosity of the oil is a function of both SRT and temperature. Viscosity decreases as either SRT or temperature increases. The viscosity of the oil produced under a given set of operating conditions will be dependent on the source sludge used. For example, under optimum operating conditions, two different sludges produced oils with viscosities of 33.7 and 52.3 centistokes.

The elemental characteristics (C,H,N,O,S) of the oil appear to be quite stable with respect to processing conditions. Some fluctuations in the carbon content are evident, but the magnitude of change is relatively small. In general, 40 to 50% of the carbon from the sludge is recovered in the oil. Oxygen is difficult to measure because an unrealistically high oxygen result will be obtained if water is present in the oil sample. Although oxygen is generally in the range of 6-9%, levels as low as 2.7% have been obtained. The elemental characteristics of the char tend to be affected more by processing conditions than do those of the oil. As the temperature increases, the carbon, hydrogen and nitrogen in the char tend to decrease.

The reaction water has a total Kjeldahl nitrogen content (TKN) of 4-6% and a total organic carbon content (TOC) of 10-18%. Based on the data currently available, there does not appear to be any relationship between TKN/TOC and operating parameters.

In general, the process has proven to be very stable, at least at bench scale. As the process variables change, the split between products also changes gradually. Similarly, the quality of the products is affected by process modifications but the magnitude of the change is small. The result of this is that over the practical range of operating conditions, the performance of the system can be described as a relatively flat plateau as opposed to a peak. In practical terms this means that if the temperature unexpectedly changes by 50°C in full-scale operation, one can expect to see this reflected in relative yields, but the process will not fail. It is also unlikely that the product qualities will change sufficiently in short periods of time to affect end uses or specifications.

IMPACT OF SLUDGE TREATMENT PRACTICES

The selection of the most appropriate sludge management scheme must consider many factors including capital cost, operation and maintenance cost, cost stability in the future, energy recovery/usage, environmental acceptability and the difference between new construction versus upgrading existing facilities. Other less tangibles include the desirability of capital versus O and M expenditures, the public perception of acceptable technology and the flexibility to respond to changing needs in the future. The impact of sludge handling and disposal practices can be illustrated by examining the four sludge management alternatives shown in Figure 13. They range from a relatively low level of technology with many years of documented experience, to a very sophisticated system which, to date, has only been proven at bench-scale. In Table 2 the four alternatives are compared on the basis of their energy recovery potential. The analysis uses a raw sludge input, for all alternatives, of 25 dry tonnes of sludge solids per day. It is assumed that sludge, char, NCG and reaction water are combusted at 75% efficiency. In order to be consistent, the methane from digestion is only allocated 75% of its gross energy, since it still has to be burned in a furnace of some nature before the energy becomes usable.

Alternative A, the application of digested sludge on agricultural land, has traditionally been the preferred method of sludge management for many municipalities. For smaller communities which have a sludge with acceptable levels of heavy metals, this is still the most cost effective method of disposal. As communities become larger, drawbacks to this system become evident. It is difficult for large municipalities to find sufficient land within a reasonable distance of the plant on which to apply the sludge. Even if the required land is available, the number of trucks needed to transport liquid sludge may create a local traffic problem which can adversely affect public relations. As municipalities become more industrialized, the potential that the sludge may not satisfy heavy metal guidelines for land application also increases. In terms of energy recovery the system is quite efficient showing a net energy of 4.06 MJ/kg of raw sludge. The reason for

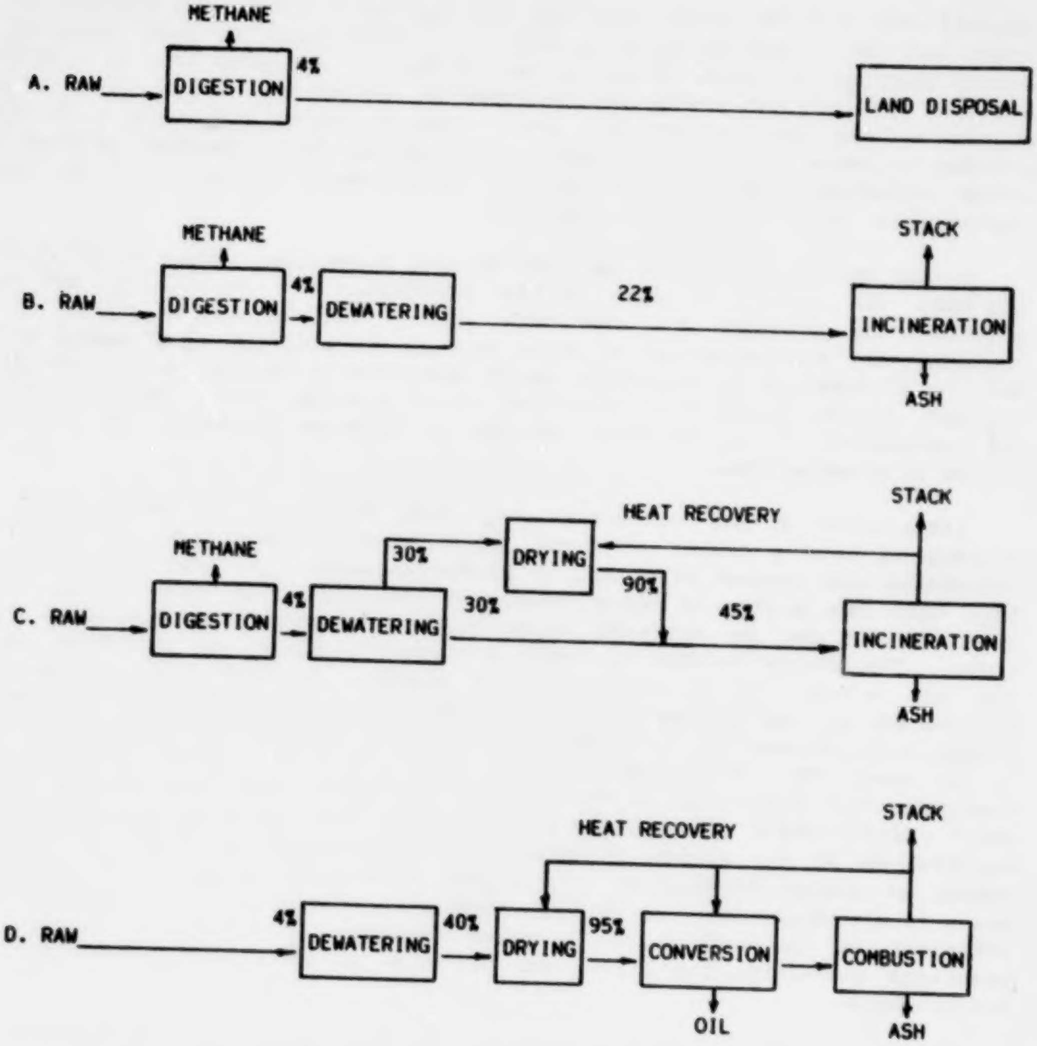
TABLE 2. ENERGY BALANCE FOR SLUDGE DISPOSAL ALTERNATIVES

ALTERNATIVE (See Figure 13)	A	B	C	D
Total Energy Available in Raw Sludge (MJ/h)	17072	17072	17072	17072
ENERGY OF PRODUCTS				
Methane (MJ/h)	4230	4230	4230	0
Oil (MJ/h)	0	0	0	8327
Char+NCG+H_2O (MJ/h)	0	0	0	5111
Digested Sludge (MJ/h)	0	5414	5414	0
ENERGY REQUIREMENTS				
Reactor/Dryer Incinerator/Combustor (MJ/h)	0	12797	7580	1739
NET ENERGY				
(MJ/h)	4230	-3063	2064	11699
(MJ/kg raw sludge)	4.06	-2.94	1.98	11.23
ENERGY RECOVERY				
(%)	24.8	0	12.1	68.5

NOTE * Net Energy = Total Energy of Products - Total Energy Requirements
* Energy Recovery = (Net Energy / Raw Sludge Energy)x(100)

this level of efficiency is that there are no large energy requirements for this alternative, although the energy required to transport the sludge to the farmland has not been accounted for. One of the major problems with methane as an energy source is that because it is difficult to store and transport, it must be utilized on-site continuously. Many sewage treatment plants find that this is not possible in summer, and consequently, flare a significant fraction of their gas. Thus, while a digester may be generating potential energy at the rate of 4230 MJ/h, the rate of utilization over the entire year may be considerably less.

Alternative B has been a common practice for many installations. The sludge is digested, dewatered to 20 to 22% and incinerated in a multiple-hearth or fluidized bed incinerator. This alternative is significantly more expensive than Alternative A and is much less energy efficient. Reference to Table 2 shows that there is a net energy deficit of 2.94 MJ/kg of raw sludge, assuming that the incinerator has been modified to burn methane as auxiliary fuel. This inefficiency is primarily due to the energy requirements to evaporate the water (78%) in the incinerator. If the energy deficit were satisfied by natural gas, this would translate to an auxiliary fuel cost of approximately $150 000 per year. The positive features are that there is a minimum quantity of material (ash) for ultimate disposal, and the majority of heavy metals will be immobilized in the ash. Due to the high energy requirements, this system is generally being phased out.


METHANE
A. RAW
DIGESTION
4%
LAND DISPOSAL
METHANE
STACK
B. RAW
DIGESTION
4%
DEWATERING
22%
INCINERATION
ASH
STACK
HEAT RECOVERY
METHANE
30%
DRYING
90%
C. RAW
DIGESTION
4%
DEWATERING
30%
45%
INCINERATION
ASH
STACK
HEAT RECOVERY
D. RAW
4%
DEWATERING
40%
DRYING
95%
CONVERSION
COMBUSTION
OIL
ASH

NOTE: (%) numbers refer to sludge solids concentrations at various points in the process.

Figure 13. Sludge disposal alternatives.

Alternative C is one approach to maintaining the same basic system as outlined above, but upgrading it in order to improve energy efficiency and subsequently reduce operation and maintenance costs. The sludge dewatering equipment is upgraded in order to achieve 27 to 30% solids in the cake on a consistent basis. A portion of the cake is then dried to 85 to 90% solids using waste heat from the incinerator. This portion is backmixed with the rest of the dewatered cake (30% solids) such that the combined sludge feed to the incinerator is in the order of 40 to 50% solids. Depending on the volatile fraction of the sludge, the cake may or may not be autogenous. The capital cost will be higher than for Alternative B due to the addition of the dryer but the energy balance is much more positive. In this case, a net energy surplus of 1.98 MJ/kg of raw sludge is produced but it should be stressed that any net energy not utilized in the process is only available as either methane gas or hot flue gas. Both of these represent a difficult problem in terms of either storage or transportation. Another problem with either Alternative B or C is that, in many cases, the public views sludge incineration as an undesirable practice.

Either system could also be used without digestion. This would probably increase the level of cake solids acheivable in dewatering and would significantly increase the available energy in the sludge going to the incinerator. The potential of using methane as auxiliary fuel would be lost and the elimination of digestion would mean that a backup method for sludge disposal during incinerator down-time would also be lost. When all factors are considered, it is not clear whether it is more economical to incinerate raw or digested sludge.

Alternative D has currently only been evaluated at bench-scale, but appears to have a number of novel aspects which could make it a publicly acceptable and economical method of sludge disposal. As mentioned above, the fact that raw sludge is being dewatered indicates that cake solids in the order of 40% can be achieved using technology such as a diaphragm filter press. The energy balance in Table 2 shows the impact on recovered energy. The net energy (11.23 MJ/kg of raw sludge) is 2.75 times higher than Alternative A, and almost six times higher than Alternative C. All process energy requirements for Alternative D could be supplied by 34% of the energy in the char, NCG and reaction water. This would leave 3372 MJ/h of energy available for other uses in the form of recovered heat, and 100% of the oil (8327 MJ/h) would be available for sale. The primary reason for the differences in the energy balances between Alternatives C and D is in the manner of energy conversion. In C the conversion is either by biological means (i.e., digestion), or by heat recovery. Neither of these methods are as efficient as the process in D which consists of catalysed vapour phase reactions converting the lipids and proteins in the sludge to straight chain hydrocarbons.

The fact that a large percentage of the energy in Alternative D is available as oil has a significant impact on the entire sludge management philosophy. Instead of having to use recovered energy in-house, which is usually the case with methane, steam, hot flue gas, and even electricity, the energy is now in a storable, transportable and potentially saleable form. Currently, the least valuable end-use for the oil appears to be as a substitute for No. 6 fuel oil. If the oil can be sold for $30/barrel, then the net revenue from a 25 tonne of dry sludge per day plant would be approximately $365 000 per year. However, the potential exists to increase end-use value, and upgrading to a transportation fuel is a possibility.

The use of a char combustor as opposed to a sludge incinerator may also have a distinct advantage with respect to public acceptance. The combustion of char may be seen to be more analagous to burning coal, rather than incinerating sewage sludge with all of the perceived associated environmental concerns. The char combustor will be similar to an incinerator in that they will produce the same amount of material for ultimate disposal and the heavy metals will, to a large extent, be immobilized in the resulting ash. A char combustor should also be considerably smaller than an incinerator to burn sludge from an equivalent sized plant because the capacity to evaporate the large amounts of water which are normally present in sludge, is not required.

Sludge management by conversion to oil will be most advantageous when considering the construction of new plants. Since the major source of the raw material for oil is the biomass from the biological treatment plant, the ideal feed stock for the process is raw sludge. This eliminates the need for the construction of digesters and can be translated into savings in capital investment for new plant construction. The process is also compatible with high-rate biological processes. One of the drawbacks of high-rate processes has always been the additional quantities of sludge generated and the corresponding increases in sludge disposal costs. By converting the excess sludge to oil, any additional cost resulting from the increased quantity requiring treatment, should be offset by the increased volume of oil produced.

CURRENT STATUS

The approach to sludge management in the sewage treatment industry has changed over the past few years and will continue to change in the foreseeable future. Considerations of energy, cost and availability have shown that many sludge handling options, which were considered state-of-the-art only a few years ago, are no longer economically justifiable. Sludge management schemes must be designed with an overall systems approach to both the solids flow and energy efficiency.

The automatic control of polymer in the conditioning/dewatering phase of sludge treatment represents an opportunity to save money and improve process performance. The basic concepts of the control logic developed at the Wastewater Technology Centre have been shown to be valid. A Canadian company is currently working on a government sponsored contract to develop a commercial prototype of the control system which should be commercially available in 1987.

The conversion of sludge to oil offers an attractive alternative to sludge options currently in operation. The conversion technology is estimated to be at least comparable to incineration in terms of capital cost and minimal negative impact on the environment. The most important advantage is that the recovered energy is in the form of oil which is storable, transportable and potentially saleable.

It is estimated that in 1985, 350 000 tonnes of sewage sludge will be incinerated in Canada. Thermal conversion of this sludge could produce 700 000 barrels of oil, with a market value of at least $21 million.

Environment Canada's long term plans are to demonstrate this technology by construction of a 25 tonne per day facility. The first component of this demonstration study has been completed,under contract, with the development of the pre-engineering data, identification of suitable sites and a thorough assessment of the process economics. Current activities are centred around the selection of a company to act as the licencee for the technology. The 25 tonne per day demonstration facility is scheduled to be operational in 1986.

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ITALIAN ADVANCES IN WASTEWATER TECHNOLOGY

by

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ITALIAN ADVANCES IN WASTEWATER TREATMENT

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ABSTRACT

Italian legislation on wastewaters control establishes fixed quality limits not dependent on the characteristics of receiving water bodies. In order to protect low receiving capacity water bodies, the limits are very restrictive, especially with regard to heavy metals and nutrients. Furthermore, typical products of the Mediterranean area, and particularly of Italy, such as olive oil, originate seasonal discharges with high BOD concentration (up to 100,000 ppm) which are poor in nutrients. These discharges are not easily treatable by means of traditional aerobic biological processes, as they require a long start-up time and very high degrees of dilution, in order to eliminate toxicity phenomena.

This situation created the necessity for the research reported herein: - heavy metals removal by advanced precipitation processes; - nutrients removal with a single sludge system without addition of external reactives; - anaerobic treatment of highly concentrated soluble wastes either in UASB reactors or mixed with domestic sludges in traditional sludge digesters.

TOXIC METAL REMOVAL AND RECOVERY FROM WASTEWATERS

Two main research projects have been devoted by the Instituto di Ricerca sulle Acque (I.R.S.A.) to this problem:

- metal precipitation using the water soluble starch xanthate, a derivative of an inexpensive natural product;
- synthesis and characterization of new Ionic Exchange (IE) materials high **with high affinity for metal ions**

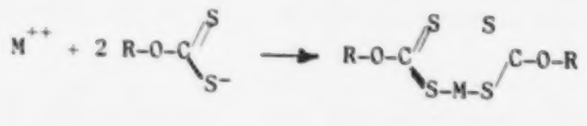
METAL PRECIPITATION WITH STARCH XANTHATE

Starch xanthate (SX) is a water soluble polymeric reagent which is **easily synthetizable starting from starch, CS_2 and NaOH aqueous solution. It shows high metal removal efficiency for Cd (II), Cr (III), Cu (II), Pb (II), Hg (II), Ag(I) and Ni(II), either separately or in combination, over a large pH range. The parameter xanthate/metal ratio is most significant both for metal removal efficiency and for solid/liquid separation efficiency, and can be controlled by a potentiometric system.**

Figure 1 report the residue concentration of Ag(I), Hg(II), Cu(II), Zn(II) as a function of the SX/metal molar ratio, after 0.45 µm filtration at constant pH = 5 (7.5 for Ag) and ionic strength 0.1 M $NaNO_3$, obtained **during batch tests.**

The data indicate that very low concentrations are reached for Ag, Hg and Cu (0.01; 0.005 and 0.09 mg Metal/l, respectively). On the contrary, the removal of Zn is not complete, and the final concentration is in order of 20 mg/l.

As far as the stoichiometry and thermodynamics of metal-xanthate systems **are concerned, literature data are available only for the metal-ethylxanthate** reaction. Preliminary numerical simulation with these data showed that neither stoichiometric nor equilibrium parameters of metal-ethylxanthate systems could be used to successfully model the behaviour of metal-starch xanthate systems, as shown in Figure 1. According to the stoichiometry of the reaction between metals and ethylxanthates, the theoretical SX/M molar ratios in the precipitated compounds should be 1 : 1 for mono-valent metals and 2 : 1 for divalent ones. For example the following reaction can be assumed for a divalent metal:



$$M^{++} + 2\,R\text{-}O\text{-}C(=S)S^- \longrightarrow R\text{-}O\text{-}C(=S)\text{-}S\text{-}M\text{-}S\text{-}C(=S)\text{-}O\text{-}R$$

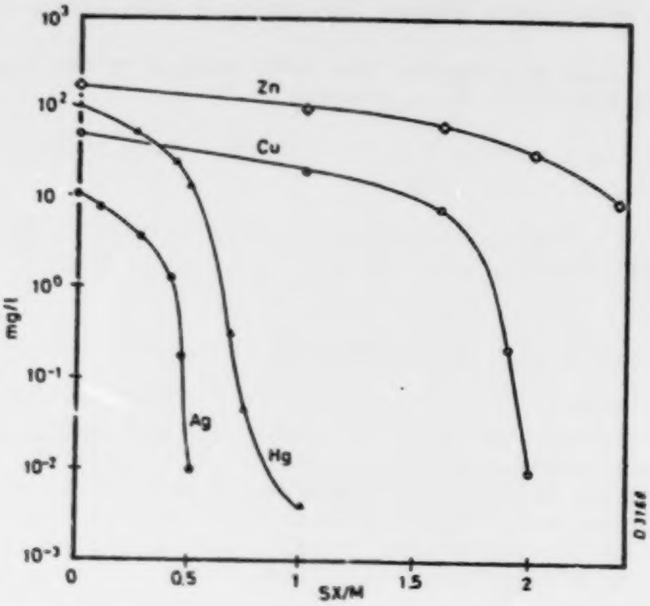


Figure 1. Effect of SX/M molar ratio on the residual metal ion concentration in solution after 0.45 μm filtration
pH = 5.0 ± 0.5 Stat (7.5 ± 0.5 for Ag)
Ionic strength = 0.1 M $NaNO_3$.

As Figure 1 indicates the best experimental SX/M ratios for a complete removal of metals are not consistent with the theoretical ones, for Ag(I) and Hg(II). In these cases the quantitative removal of the metals from the solution (> 99.9%) is reached when the SX/M ratios are 0.5 and 0.8, respectively.

Experimental work was carried out in order to determine metal binding capacities of the starch xanthate and conditional formation constants of the metal-starch xanthate insoluble complexes.

Figure 2 shows an example of the the Scatchard pilot extrapolation method applied to the results of the potentiometric filtration of starch xanthate solutions with metal ions. The Scatchard extrapolation method evidenced two metal binding mechanisms, the first related to chemical precipitation of the metal ions with xanthate groups and, the second, to the adsorption of metal ions on the precipitate.

The determined stability constants and complexing capacities of starch xanthates with heavy metals were then incorporated in a computer program, in

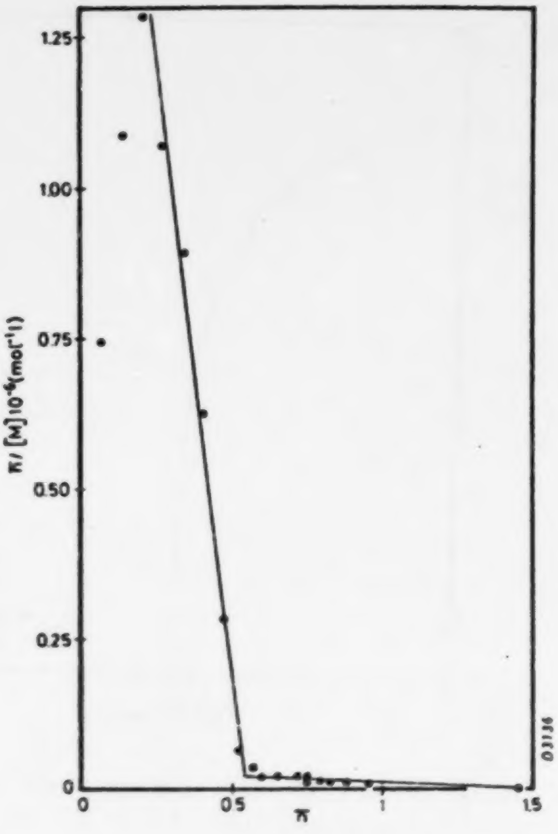


Figure 2. Scatchard plot for the binding of Cd(II) by ethylxanthate at pH 7.5 and 0.1 M $NaNO_3$.

order to simulate the fate of a metallic ion in wastewater after treatment with SX.

As an example, Figure 3 compares theoretical and experimental trends of the residual silver concentration after treatment of uncomplexed Ag^+ ions (from $AgNO_3$ salts) of initial concentration 10^{-4} M, corresponding to 10.7 mg/l as Ag. The curve represents the theoretical behaviour, assuming $K_1=10^{13}$; $n_1=2$; $K_2=6.9\times10^3$; $n_2=2.5$. The experimental points, determined either by potentiometric ISE measurements or by AA analysis after 0.45 μm filtration, are in good agreement with the predicted behaviour.

Further experiments are being run in order to compare the results of the theoretical simulation of the process with the experimental ones, particularly in the case of the presence of metal complexing agents in wastewaters.

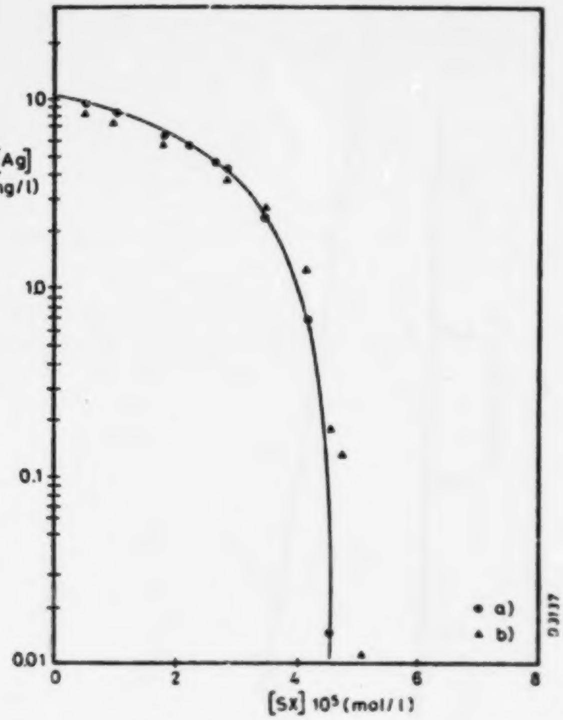


Figure 3. Silver (from $AgNO_3$ salt) removal with starch xanthate.
Starting solution: $AgNO_3$ 1.0×10^{-4} M; 0.1 M $NaNO_3$;
pH = 7.5; $[SX] = 1.18 \times 10^{-3}$M.
● from potentiometric data
▲ AA determinations
The continuous line represents the calculated curve.

The behaviour of the system is completely different when complexed metal ions are to be precipitated. For the sake of example, Figures 4 and 5 report the distribution diagram of the hydrolysis products and chlorocomplex species of Hg(II) in ionic strength 0.1 M $NaNO_3$ and 0.1 M NaCl, respectively. Working at pH = 5, the prevailing species in solution is $Hg(OH)_2$ in the first case, while the sum of $HgCl_3^-$ and $HgCl_4^{2-}$ accounts for about 60% of the total Hg in the second case. Figure 6 shows the difference in the kinetics of precipitation of the mercury at pH = 5 starting from the hydroxocomplexes (curve a) and from the chloro-complex (curve b). The removal of 99.9% of Hg is obtained after 5 minutes and 35 h, respectively. The slow kinetics is probably to be ascribed to the repulsive electrostatic forces between the negative xanthic groups and the anionic chlorocomplex species of mercury.

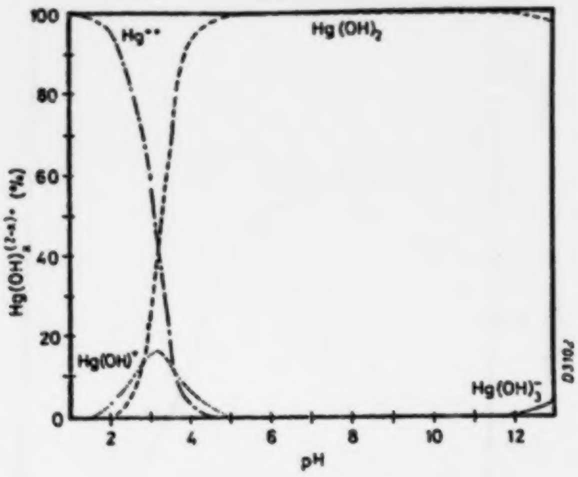


Figure 4. Theoretical distribution of hydrolysis products of Hg(II) in NaNO$_3$ 0.1 M test solutions.

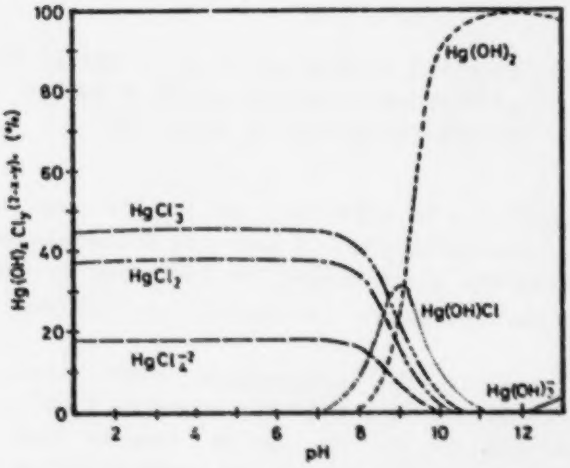


Figure 5. Theoretical distribution of hydrolysis products and chlorocomplexes of Hg(II) in 0.1 M NaCl test solutions.

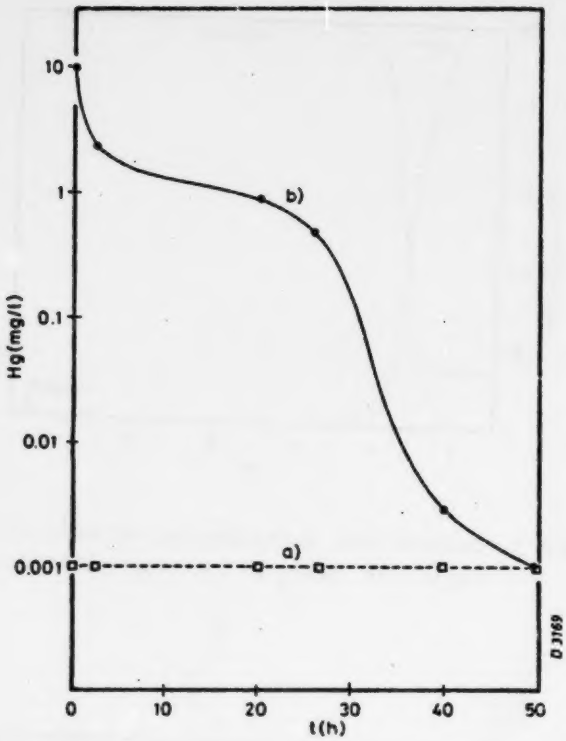


Figure 6. Kinetics of precipitation of Hg(II) at pH = 5 Stat.
a) hydroxide-complex in 0.1 M $NaNO_3$
b) chloro-complex in 0.1 M NaCl

It is interesting to note that, while metal speciation greatly affects the kinetics of precipitation, it does not influence the solubility of the mercury xanthate: the quantitative precipitation of the metal from 0.1 M $NaNO_3$ or 0.1 M NaCl solutions is obtained at the same ratio SX/Hg = 0.8.

Table 1 summarizes the experimental results obtained in batch tests when the viscous SX(0.7 mmol S/g) was added to 1 dm^3 of solutions containing dissolved metals Zn, Cu, Cd, Hg, and Ag (one at time) at pH stat = 5. The final concentrations of the metals are still found to be below the limits of current Italian Legislation. Also the optimum polycation dosage is reported in Table 1 at the ionic strength indicated. The operative removal capacity in batch tests for Zn, Cu, Cd, Hg and Ag was found to be 19.1; 22.2; 39; 143; 154 g of metal/kg of SX (viscose), respectively.

The small amounts of sludge obtained after precipitation with SX are

TABLE 1. EXPERIMENTAL RESULTS OBTAINED IN BATCH TESTS WITH METAL ION SOLUTIONS (SEPARATE EXPERIMENTS) AT pH = 5 STAT. (INITIAL STARTING VOLUME = 1 dm^3. SX VISCOSE = 0.7 mmol/g AS SULFUR TOTAL REACTIVE).

	Zn	Cu	Cd	Hg	Ag
Feed conc. (mg/l)	500	50	53	100	11
SX/M ratio (mol/mol)	2.4	2.0	2.0	1.0	0.5
Residual conc. after filtration (0.45 μm) (mg/l)	10	0.01	0.02	0.001	0.01
Optimum polyelectrolyte dosage (mg/dm^3 PC-7)	100^{*}	10^{**}	7^{+}	30^{++}	12^{+}
Operative removal capacity (g/Kg SX Viscose)	19.1	22.2	39	143	154

*: Ionic strength = 0.3 M NaCl; **: 0.04 M NaNO$_3$; +: 0.1 M NaNO$_3$; ++: 0.005 M NaNO$_3$.

easily dewaterable by traditional techniques (filtration, mechanical dehydration). Preliminary tests carried out with acid solutions to recover metals in solution gave unsatisfactory results. An oxidant treatment with NaClO solution and iodine to lower the pH below 3 gave quantitative recovery, as reported on Figure 7, in the case of mercury sludge. In this case, the reaction proceeded the formation of insoluble starch xanthide, a non-toxic residue disposable without difficulty.

The SX process is now being tested in a pilot plant (1.5 m^3/h), Figure 8,on a real chlor-alkali wastewater in order to verify its applicability from the technical and economic point of view.

NEW I.E. MATERIALS FOR METAL ION UPTAKE

Two main types of materials are being investigated: the water insoluble cellulose xanthate and the copolymer Poly [(N-Dithiocarboxylato)-iminoethenhydrogenoiminoethene](PIED). The water insoluble cellulose xanthate (ICX) can be used as a chelating ion-exchange resin, characterized by relatively low costs of synthesis. The ICX can be synthetized slightly modifying the viscose synthesis procedure in the rayon process.

The research was initially aimed at finding the best operating conditions for the synthesis in order to obtain an insoluble material with high

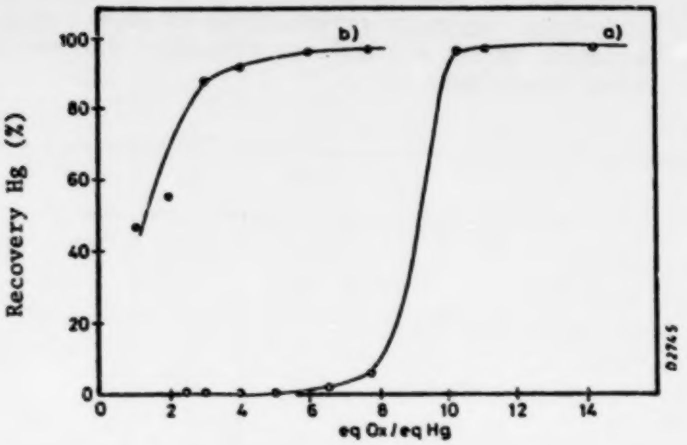


Figure 7. Recovery of mercury from sludge by chemical oxidation at pH = 3.5.
a) NaClO; b) I_2.

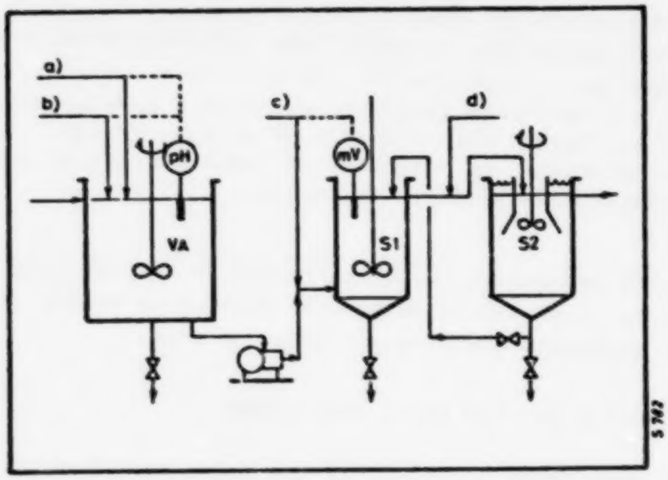


Figure 8. Lay-out of the plant.
VA = Storage tank; S1 = Precipitation reactor; S2 = Settling tank; a) = Acid; b) = Base; c) = Starch xanthate; d) = Polyelectrolyte.

ion-exchange capacity. Under optimal conditions the final compound had a metal **extraction capacity in the range of 1 to 2.5 meq/q. The ICX was obtained** both in Ma and in Mg-form. The Mg-ICX (dried, in powder form) proved to be stable for 1 year at ambient temperature.

Table 2 reports the results obtained with column operations with a bed of Mg-ICX as chelating resin. Working with feed solutions of 30 mg/l of each metal and at a flow rate of 10 BV/h, a leakage corresponding to the units imposed by law for Cu, Ag, Cd and Hg was reached up to 65; 168; 130 and 45 V/V_R, respectively.

TABLE 2. EXPERIMENTAL RESULTS OBTAINED WITH CELLULOSE XANTHATE PROCESS IN COLUMNS

ICX-Mg (Total capacity = 1.2 mmol/g).
Flow velocity = 10 BV/h; Separate experiments for each metal.

	Cu	Ag	Cd	Hg
Feed concentration (mg/l)	30	30	30	30
Initial pH	6.5	6.6	7.0	7.2
ICX-Mg used (g)	8.4	7.6	7.0	7.3
Volume of ICX-Mg (cm^3)	40	30	30	30
Concentration limits in Italy (mg/l)	0.1	0.2*	0.02	0.005
Water treated (V/BV)**	65	168	130	45
Operative removal capacity (mg of metal/g ICX-Mg)	9.28	19.9	16.7	5.55
(mmol metal/g ICX-Mg)	0.15	0.18	0.15	0.028

*: USA Regulation (1982)
**: to obtain a leakage corresponding to the maximum metal concentration permitted by law.

The corresponding operative removal capacities are 9.28; 19.9; 16.7 and 5.5 mg of metal/g of ICX.

It is interesting to note that columns of CX can be used to "polish" **very low concentrations of metals in solution. By way of example, Figure 9**

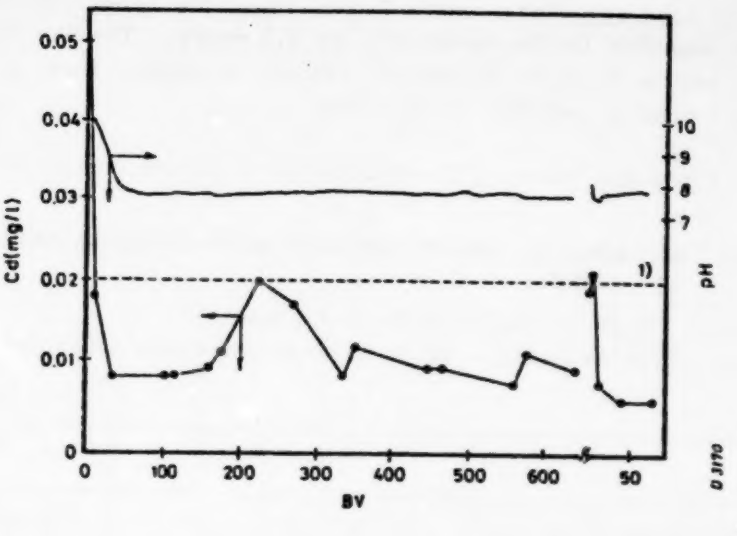


Figure 9. Removal of trace concentrations of Cadmium by treatment with ICX-Mg in column operation.
Initial Cd = 0.054 mg/dm^3; Flow rate = 10 BV/h; 1: Limit by law.

reports the effluent concentration of Cadmium, fed at a velocity of 10 BV/h and at initial concentration of 0.054 mg/l, as a function of the treated bed volumes.

The data show that the Cd concentration in the product water is below the 0.02 mg/l limit set by Italian Legislation. Furthermore, the removal efficiency of the ICX-Mg is unchanged after a 69-day interruption of the run. This is a confirmation of the good stability of this material with time, as reported previously.

The exhausted ICX materials were then treated for metal recovery, with either chemical or thermal treatment.

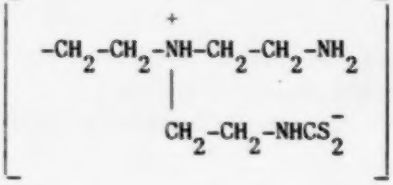
Table 3 shows the metal yields obtained by treating different ICX sludge exhausted with Cu, Ag and Cd: 70-90% metal recovery was achieved.

Finally, the synthetic copolymer PIED was investigated, in cooperation with the Chemical Department of Reading University (U.K.), for selective metal extraction from wastewaters.

TABLE 3. RECOVERY OF METALS FROM SLUDGE IN THE CX-Mg TREATMENT BY BURNING AND CHEMICAL OXIDATION

	Cu	Ag	Cd
Metal in sludge (mg)	121.5	246	152.5
Amount of sludge (g)	8.4	7.6	7.0
Metal recovery (mg)			
a) by burning (mg)	108	219	118
(%)	89	89	77
b) by oxidation with NaClO (mg)	87	--	136
(%)	72	--	89

The studied material is a copolymer which is prepared from poly(iminoethene) and carbon disulphide. An idealised formulation of the repeating unit of PIED is given below:



$$\left[\begin{array}{l} -CH_2-CH_2-\overset{+}{N}H-CH_2-CH_2-NH_2 \\ \qquad\qquad\quad | \\ \qquad\qquad\quad CH_2-CH_2-NHCS_2^- \end{array}\right]$$

The N-dithiocarboxylate groups are thought to be mainly on the primary amine groups. In addition to the $-NHCS_2^-$ groups, there are the remaining primary amine groups and the other nitrogen-containing groups which can bonded to the metal ion.

Figure 10 show that PIED rapidly extracts cadmium from aqueous solutions. The addition of PIED (∼ 1g) to a solution (100 ml) containing cadmium (10.2 mg/l) reduce the concentration to 0.001 mg/l in ten minutes. Moreover in accordance with the fact that N-dithiocarboxylates had a greater affinity for cadmium than zinc, it was found that PIED can perform a useful separation of the two metal ions. The results in Figure 11 refer to the extraction from solutions containing cadmium (11.2 mg/l) and zinc (13.0 mg/l) at pH 2 (H_2SO_4) as commonly experienced in waste waters containing both metal ions. The salt Zn-PIED was used with different loadings of cadmium. The lower the loading of cadmium the faster the kinetics, but the presence of zinc does not influence the kinetics of cadmium uptake on PIED.

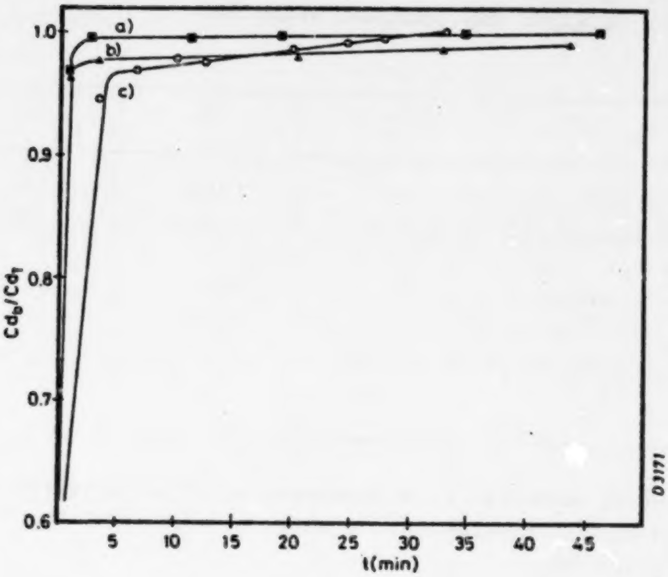


Figure 10. Uptake of Cd(II) by PIED at pH 5.5 as a function of time. Ionic medium 0.1 M $NaNO_3$

a) 0.09 mmol Cd added/g PIED
b) 0.392 " " " "
c) 0.72 " " " "

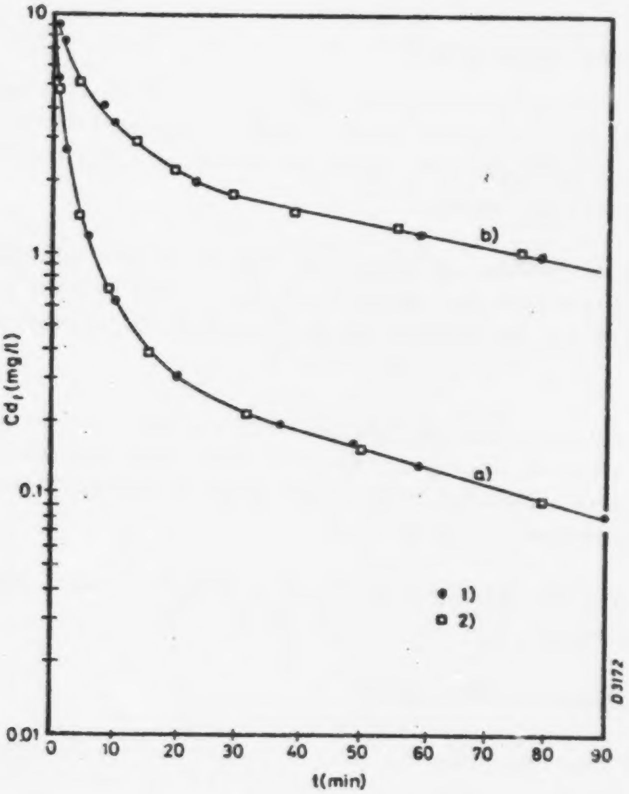


Figure 11. Residual cadmium concentration in solution after treatment with Zn-PIED (0.100 g) as a function of time.
Ionic medium 0.1 M $NaNO_3$; pH = 2 (H_2SO_4)

●: Initial (Cd) = 11.2 mg/dm^3

□: Initial (Cd) = 11.2 mg/dm^3 and (Zn) = 13.0 mg/dm^3

a) Cd Loaded = 0.10 mmol Cd/g Zn-PIED
b) Cd Loaded = 0.50 mmol Cd/g Zn-PIED

ANAEROBIC PROCESS DEVELOPMENT

In recent years considerable interest has been focused on anaerobic treatment of a wide range of waste waters, ranging from high strength effluents to very diluted ones, as an interesting alternative to high energy consuming aerobic processes.

The main advantages of anaerobic digestion are well known: low high-grade energy requirements for process operation and in many cases, a net overall energy balance; low production of well stabilized excess sludge; low capital cost.

The main draw-backs consist of start-up and process control problems, mainly due to the slow growth rates of some anaerobic bacteria and to the still inadequate understanding of the complex interactions between biological and the physicochemical factors.

Several Italian Research Institutes are developing innovative anaerobic research processes.

Istituto di Ricerca sulle Acque

Most of the experimental activity carried out or currently in progress at this Institute on anaerobic digestion is related to the treatment of olive oil mill waste waters, which considerably increase the polluting load during the milling season in the Mediterranean area and in the Apulia region, where the Bari IRSA laboratories are located.

With reference to the anaerobic treatment of olive oil mill wastewaters, **IRSA has developed high rate UASB (Upflow Anaerobic Sludge Bed) reactors for** digesting these concentrated effluents (COD in the range 50-200 kg/m^3).

UASB reactors are expanded bottom-fed sludge vessels; there is no mechanical stirring in the system and this fact, as well as the relatively high upflow velocity, promotes the formation of well settling sludges.

Treatment of olive oil mill waste waters in UASB digesters was made possible by dilution with well water. For full scale applications, dilution by sewage will be used as it also eliminates nitrogen deficiency in the waste.

Experiments have been performed both on laboratory and pilot-scale reactors (volume 15 l and 5 m^3, respectively) maintained under mesophilic conditions (35°C).

Most start-up problems have been solved by starting with a very diluted waste (about 5 kg COD/m^3) and then increasing the concentration by steps of 2, 5 kg COD/m^3 to a final concentration of about 15 kg COD/m^3, while also adding suitable amounts of nitrogen (available nitrogen in the waste is deficient) and alkalinity (sodium bicarbonate, soda and calcium hydroxide) to the feed.

The hydraulic residence time (HRT) was kept constant at 1 d during the tests. The volumetric loading rate was increased from 5 kgCOD/(m^3.d) to 16 and 21 kgCOD/(m^3·d) for the pilot and the laboratory reactor, respectively.

Removal efficiencies in the range of 70 - 75% on the COD were obtained, as well as specific gas production rates of the order of 4 to 6 $m^3/m^3r\cdot d$.

These results can be justified by the high concentration of active biomass which built up in the reactor and by the beneficial effect which the added chemicals seem to have on the net microbial growth rates.

Sludge granulation as achieved in Dutch UASB digesters, fed on carbohydrate wastes, was not obtained but, even so, the settleability of the sludge proved very good.

Experimental results related to a start-up of a 5 m^3 pilot reactor are reported in Figure 1, where loading rates are given as kg TOC/(m^3·d). Loading rates as COD can be obtained by multiplying TOC values by 2.5 - 3. From the diagram it can be seen that after about 30 days the system has been overloaded with a consequent increase of volatile organic acids (TVA).

Present research is aimed at defining a start-up procedure to minimize chemical consumption and energy (heating) requirements during the transient operation until full load conditions are reached.

The experiments are currently being carried in laboratory and pilot scale plants at the IRSA laboratory, and will be subsequently replicated on a test bed plant (two 750 m^3 digesters) the construction of which will be funded by the Apulia Regional Authorities within 1986 in the municipality of Pallo del Colle.

The design of this demonstration plant has been made by IRSA and by regional technical engineers (as far as the sizing of the reactors and the concrete structures, respectively, are concerned).

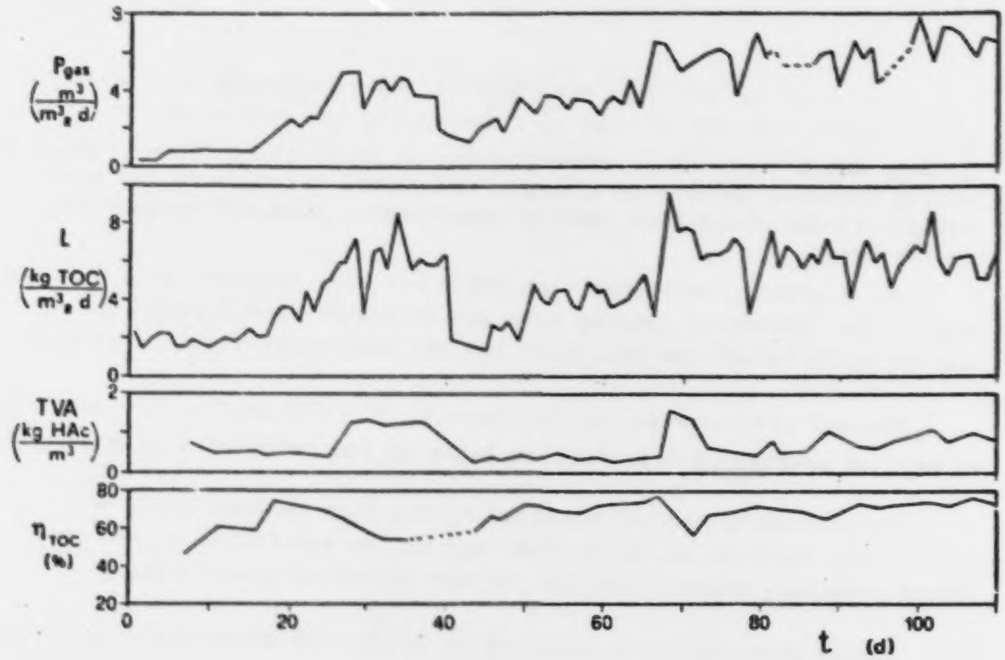


Figure 12. Pgas = Specific Biological gas production; L = Specific load; TVA = Volatile organic acids; TOC = Removal efficiency.

Experiments are also being performed on the direct anaerobic treatment at ambient temperature of raw sewage in sludge blanket reactors. The most interesting feature of this process is a much lower production of sludge than aerobic systems (e.g.: activated sludge and trickling filters). Direct anaerobic treatment of raw sewage is being investigated on laboratory UASB reactors and in the near future the tests will be extended to a 5 m^3 pilot plant.

Results obtained on the laboratory reactor are promising, as 50-60% of the polluting load can be removed by this process.

Agip Giza S.p.A..

This Company, in cooperation with the ENI Research Laboratories (ENI RICERCHE), has developed fixed film anaerobic digesters (anaerobic filters) for wastewaters with a prevalently soluble pollution load.

The main advantantages of fixed film reactors are related to the high sludge retention times, the high sludge concentrations that can be attained and maintained to their capacity to withstand very high temporary hydraulic and organic overloadings. Two full scale plants have been built. The first one, made of two 1500 m^3 anaerobic filters using quartz rock as filling media, has been successfully operating on a sugar factory for several years. The second one, treating vegetable canning industry effluents, is a 300 m^3 anaerobic filter and was started up in Spring 1985.

The anaerobic filters in the sugar factory treat the regeneration streams from ion exchange resin columns that purify the sugar juice from non crystallizable organic (mainly proteinaceous) compounds.

The operating conditions are as follows: loading rate 9 kg COD/(m^3·d), hydraulic retention time: 2 days, specific gas production 2.3 m^3/(m^3·d) with 70% methane, removal efficiency 60% on the COD. All these data refer to the full volume of the filters, which have a void fraction of approximately 50%.

ENI Ricerche

Eni ricerche has carried out the R. & D. for the above mentioned anaerobic filters on sugar wastewaters up to the pilot plant scale. A trucked pilot plant has been designed and built for the purpose of carrying out treatability experiments in the factories producing the effluents to be tested.

Eni ricerche is presently developing anaerobic fluidized beds using sand particles as supporting media.

Very interesting results have been obtained using laboratory scale reactors. At loading rates of the order of 150 kg COD/(m^3·d) and retention time of 0.11 days, specific gas production rates of 26.5 m^3/(m^3.d) and COD efficiencies of the order of 45% have been achieved.

BIOLOGICAL NITROGEN REMOVAL FROM INDUSTRIAL WASTEWATERS

Within the framework of biological nitrogen removal, the aim of this work was to verify the applicability of single sludge systems (see Figure 13) for treatment of high strength ammonia industrial wastewaters.

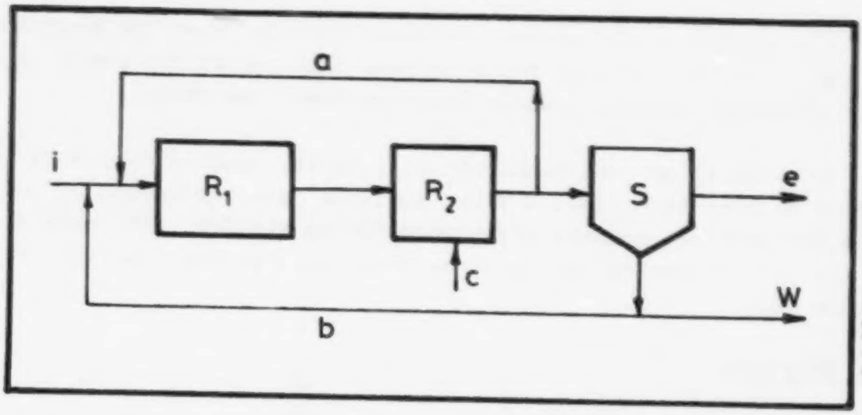


Figure 13. Flow-sheet of single sludge anoxic-aerobic process. i: influent; e: effluent; a: nitrified mixed liquor recycle; b: sludge recycle; W: waste sludge; R_1: an oxic reactor; R_2: aerobic reactor; S: settling tank.

Effective application of such a system is dependent on the value assumed by denitrification kinetics when internal carbon is used as electron donor substance; this means that the rate of this process must be high enough to be of industrial interest.

Furthermore, in the case of industrial wastewater in which inhibitors for nitrifying bacteria are present, the nitrification stage is the critical phase of the whole process and ammonia oxidation is possible only if the wastewaters are diluted. As inhibition problems are independent of the chosen process scheme, the single sludge system is in any case preferable to separate systems, and affords considerable saving of primary and secondary energy.

The wastewaters examined (see Table 4 for typical composition) are representative of two quite distinct categories: slaughter-house discharge is characterized by high biodegradability and the absence of inhibitory compounds; coke oven liquid wastes contain typical lowly biodegradable substances

TABLE 4. TYPICAL COMPOSITION OF WASTEWATERS

Slaughter-house			Coke plant	
Parameter (mg/l)	Non filtered sample	Filtered sample	Parameter (mg/l)	Non filtered sample
COD	3,070	2,080	TOC	3,300
BOD_5	2,050	1,350	Phenols (Total)	2,500
TOC	-	670	NH_4-N	3,800
TKN	260	240	Cl^-	3,000
NH_4-N	-	225	SS	0
SS	610	-		

and inhibitory compounds. The findings can therefore be extrapolated to wastewater that have intermediate characteristics with respect to the two effluents studied, thereby extending the applicability of the results obtained.

Results

The experimental work, which takes in various sets of tests run in both bench and pilot scale, is summarized in the data reported in Tables 5 and 6. These data clearly show the applicability of single sludge anoxic-aerobic systems for the biological treatment of both wastewaters studied.

As can be seen, satisfactory results have been also obtained with coke-oven liquor. After suitable dilution, good removal efficiencies for carbonaceous substances (phenols and thiocyanates) have been achieved, as well as for nitrification. As far as denitrification efficiency is concerned, the results show that the NO_3-N removal is the maximum that can be obtained with a wastewater with such a phenol/nitrogen ratio[1].

The process parameters obtained from the continuous tests of Tables 5 and 6 and, when necessary, confirmed by supplementary batch tests[2], allowed

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[1] This ratio (~ 0.7) is considerably lower than the specific phenol consumption ratio found in anoxic reactor (1.7).

[2] Since in completely mixed biological reactors, the substrate concentration in the effluent is practically the same as in the reactor, the rate of the process could be kinetically limited by one or more substrates.

TABLE 5. MEAN WORKING CONDITIONS AND RESULTS WITH SLAUGHTER-HOUSE WASTEWATER

	Parameter		Feed	Anoxic reactor or A. reactor outlet	Aerobic reactor or A. reactor outlet
Analytical data	COD	mg/l	2,080	510	256
	BOD_5	mg/l	1,350	-	19
	TOC	mg/l	670	163	76
	TKN	mg/l	240	87	15
	NH_4-N	mg/l	225	66	0
	NO_3-N	mg/l	0	0	58
Working conditions	Volume	l		670	2,670
	Hydraulic retention time	h		4.5	17.8
	Sludge age	d		1.1	4.6
	Biomass concentration	mg MLSS/l		4,920	4,870
	pH			8.1	7.6
	Temperature	°C		20	20
	Dissolved oxygen	mg/l		0.2	3.0
	Biomass nitrogen content	% SS		6.9	7.3
	VSS/SS			0.79	0.69
	Nitrif. mixed liquor rec. rat.			1.2	
	Sludge recycle ratio			1	
Process parameter	Denitrification rate	kg NO_3-N/kg VSS·d		0.19	
	Net growth yield coefficient	kg VSS/kg COD solub.		0.34	
Process performance	COD removal efficiency	%	88		
	Nitrification efficiency	%	100		
	Nitrogen removal efficiency	%	74		

TABLE 6. MEAN WORKING CONDITIONS AND RESULTS WITH SLAUGHTER-HOUSE WASTEWATER

	Parameter		Feed	Anoxic reactor or A. reactor outlet	Aerobic reactor or A. reactor outlet
Analytical data	Phenols (total)	mg/l	400	28	20
	CNS⁻	mg/l	40	1	0.5
	NH_4-N	mg/l	600	300	10
	NO_2-N	mg/l	0	3	3
	NO_3-N	mg/l	0	78	374
Working conditions	Volume	l		5	7
	Hydraulic retention time	h		20	28
	Sludge age	d		40	47
	Biomass concentration	mg MLSS/l		2,720	2,310
	pH			7.5	7.5
	Temperature	°C		25	25
	Dissolved oxygen	mg/l		0	2.5
	Biomass nitrogen content	% SS		8.5	8.5
	VSS/SS			0.86	0.86
	Sludge recycle ratio				1
Process parameters	Denitrification rate	kg NO_3-N/kg VSS·d		0.11	
	Nitrification rate	kg NH_4-N.kg VSS·d		0.25	
	Specific phenol consuption ratio	kg C_6H_5OH/kg NO_3-N		1.7	
	Net growth yield coefficient	kg VSS/kg C_6H_5OH		0.13	
Process performance	Phenol removal efficiency	%	95.0		
	Nitrification efficiency	%	98.3		
	Nitrogen removal efficiency	%	35.8		

the plants to be designed and the costs estimated once the flowrate and the concentration of pollutants were known.

Biological reactor design

Table 7 shows the flow-rates and concentration figures assumed for the dimensioning of full-scale plant for both the wastewaters studied.

TABLE 7. DESIGN DATA

Wastewater / Parameter	Slaughter-house	Coke plant
Flow rate (m^3/d)	4,000	250
Ammonia concentration (mg NH_4-N/l)	300	3,800
Ammonia load (kg NH_4-N/d)	1,200	950

More specifically, for the slaughter-house wastewaters, the economic analysis refers to plants catering for 10^5 equivalent inhabitants (referred to nitrogen). Assuming 12 g N/d·inhabitant, the total nitrogen that must be removed is : $12 \cdot 10^{-3} \cdot 10^5 = 1{,}200$ kg N/d and the related flow rate : 1,200 kg N/d : 0.3 kg N/m^3 = 4,000 m^3/d.

As far as the coke oven wastewater is concerned, reference is made to a **discharge treatment plant that produces 1,000 t of coke a day. The discharge** produced is assumed to be 0.25 m^3 of discharge for every t of coke and so the flow rate will be : $1{,}000 \cdot 0.25 = 250$ m^3/d.

Hydraulic residence times, sludge ages and recycle ratios can then be calculated (see Table 8) using the model reported by Ramadori (1).

TABLE 8. DIMENSIONING OF BIOLOGICAL REACTORS

Wastewater Parameter	Slaughter-house	Coke plant
Hydraulic retention time in the anoxic reactor	6.7 h	38 h
Hydraulic retention time in the aerobic reactor	14.4 h	21 h
Sludge age (total)	5.9 d	87 d
Nitrified mixed liquor recycle ratio	13.3	0
Sludge recycle ratio	1.0	2.0

Technical and economic evaluations of a full-scale plant

With regard to the schemes in Figure 14, which also include the sludge treatment section, Table 9 and 10 summarizing the values of the design parameters for the various units considered. These values result from the experimental work summarized in 3.1 and from the literature (2), (3).

Plant costs

Plant costs for each operating unit have been obtained from the functions reported in Table 11. Plant costs are expressed as a functions of parameters chosen as variables. For the sake of example, the costs of civil works for biological reactors (both anoxic and aerobic) are expressed as a

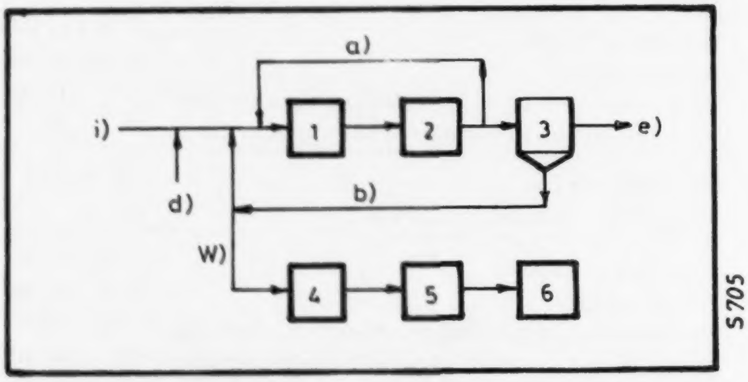

Figure 14. Process flow-sheet of full scale plant. a: influent; b: dilution water (coke plant wastewater only); e: effluent; W: waste sludge; r: sludge recycle; r': nitrified mixed liquor sludge (slaughter-house wastewater only); 1: anoxic reactor; 2: aerobic reactor; 3: settling tank; 4: pre-thickner; 5: anaerobic digester (slaughter-house wastewater) or aerobic digester (coke plant wastewater); 6: post-thickner.

TABLE 9. DIMENSIONING PARAMETERS FOR COMPONENT UNITS RELATED TO SLAUGHTER-HOUSE WASTEWATER TREATMENT

Unit	Parameter	
Anoxic reactor	Biomass concentration*	: 4,000 mg MLSS/l
	Denitrification rate	: 0.2 kg $N\text{-}NO_3$/kg VSS·d
	Specific BOD_5 consumption ratio	: 2.5 kg BOD_5/kg $N\text{-}NO_3$
	NO_3-N in the effluent	: 0 mg/l
	Specifing stirring power installed	: 15 W/m^3
	Net growth yield coefficient	: 0.4 kg VSS/kg COD soluble
Aerobic reactor	Biomass concentration	: 4,000 mg MLVSS/l
	Minimum sludge age	: 4 d
	Dissolved oxygen	: 2 mg/l
	Oxygen required for nitrification	: 4.6 kg O_2/kg $N\text{-}NH_4$
	Mechanical efficiency:	
	oxygenation	: 1.55 kg $O_2/kW_{inst}\cdot h$
	BOD_5 removal	: 1.26 kg $BOD_5/kW_{inst}\cdot h$
	TKN in the effluent	: 15 mg/l
	COD in the effluent	: 256 mg/l
Settling tank	Hydraulic retention time	: 4 h
	Overflow rate	: 0.4 m/h
	Sludge recycle ratio	: 1
Pumping station	Recycle ratio	: 13.3
	Pump pressure head	: 0.2 bar
	Pump efficiency	: 0.70
Pre-thickener	Residence time	: 38 h (1.58 d)
	Solids load	: 30 kg $SS/m^2\cdot d$
	Concentration of sludge before thickening	: 1% (~ 10 kg SS/m^3)
	Concentration of sludge after thickening	: 3% (~ 30 kg SS/m^3)
Anaer. dig.	Residence time	: 480 h (20 d)
	Volatile solids reduction	: 50%
Post-thickener	Residence time	: 38 h (1.58 d)
	Solid load	: 63.6 kg $SS/m^2\cdot d$
	Concentration of sludge before thickening	: 1.8% (~18 kg SS/m^3)
	Concentration of sludge after thickening	: 4% (~40 kg SS/m^3)
Belt-press	Operating time	: 8 h/d

***Biomass characteristics: VSS/SS = 0.80; Nitrogen ponderal fraction = 0.075**

TABLE 10. DIMENSIONING PARAMETERS FOR ALL COMPONENT UNITS RELATED TO COKE PLANT WASTEWATER TREATMENT

Unit	Parameter	
Equalization tank	Hydraulic retention time	4 h
	Specific stirred power installed	15 W/m^3
Pumping station	Pump pressure head	0.6 bar
	Pump efficiency	0.7
Anoxic reactor	Biomass concentration	3,000 mg SS/l
	Denitrification rate	0.05 kg NO_3-N/kg VSS·d
	Specific phenol consumption ratio	1.7 kg phenols/kg NO_3-N
	Specific stirring power installed	15 W/m^3
	Net growth yield	0.2 kg VSS/kg phenols
Aerobic reactor	Biomass concentration*	3,000 mg SS/l
	Nitrification rate	0.25 kg NH_4-N/kg VSS.d
	Oxygen required for nitrification	4.6 kg O_2/kg NH_4-N
	Efficiency of oxygenation	1.6 kg O_2/kW·h
Settling tank	Overflow rate	0.5 m/h
	Hydraulic retention time	7 h
Pumping station	Recycling ratio	2
	Pump pressure head	0.3 bar
	Pump efficiency	0.70
Pre-thickner	Residence time	20 h
	Solid load	30 kg SS/m^2·d
	Concentration of thickned sludges	20 kg SS/m^3
Aerobic-digester	Residence time	12 d
	Specific oxygen consumption ratio	2.3 kg O_2/kg VSS
	Mechanical efficiency of oxygenation	1.6 kg O_2/kW·h
	Volatile solids reduction	50%
Drying bed	Specific area	200 m^2/1,000 inhab.
	Equivalent inhabitants	0.08 kg SS/inhab.

* Biomass characteristics: VSS/SS = 0.85; Nitrogen ponderal fraction = 0.085

TABLE 11. COST FUNCTIONS FOR CIVIL WORKS AND ELECTROMECHANICAL EQUIPMENT

Operating units	Cost functions	
	Civil works	Electromech. equipment
Equalization tank	$C = 0.308\ V^{0.86}$	$C = 3.332\ W^{0.82}$
Pumping station	———	$C = 0.566\ Q^{0.62}$
Anoxic reactor	$C = 0.308\ V^{0.86}$	$C = 3.332\ W^{0.82}$
Aerobic reactor	$C = 0.308\ V^{0.86}$	$C = 3.332\ W^{0.82}$
Settling tank	$C = 0.882\ V^{0.74}$	$C = 2.702\ A^{0.88}$
Recycling pumping station	———	$C = 0.566\ Q^{0.62}$
Thickner	$C = 1.162\ V^{0.71}$	$C = 3.668\ A^{0.86}$
Aerobic digester	$C = 0.37\ V^{0.84}$	$C = 2.5\ W^{0.88}$
Anaerobic digester	$C = 0.204\ V^{0.916}$	$C = 0.370\ V^{0.853}$
Drying bed	$C = 0.165\ S^{0.85}$	———
Beltpress	$C = 2.97\ Q + 64.8$	$C = 13.47\ Q + 114.5$
Electr. equip. and hydr. network	———	$C = 0.23\ Ct$
Accessory works	$C = 0.11\ Cg$	———

A: transversal area; C: cost (10^6 Italian liras); Cg: total plant cost (10^6 Italian liras); Ct: total cost plant without the accessory works (10^6 Italian liras); Q: flow rate ($m^3 \cdot h^{-1}$); S: drying surface (m2); V: volume (m^3), W: power installed (CV).

function of the relative volumes while for electromechanical equipment, the costs are expressed as a function of installed power. The functions in Table 11 have been obtained from correlations with a statistical processing of cost data from 35 treatment plants throughout Italy and from design estimates (3).

Costs are referred to October, 1982.

Table 12, which summarizes total plant costs, shows the figures of $3{,}434 \cdot 10^6$ and $1{,}638 \cdot 10^6$ Italian liras for slaughter-house and coke-oven wastewaters, respectively.

TABLE 12. CAPITAL COSTS (10^6 ITALIAN LIRAS)

Operating units	Slaughter-house wastewater		Coke plant wastewater	
	Civil works	Electrom. equipment	Civil works	Electrom. equipment
Equalization tank	–	–	40	14
Pumping station	–	–	–	8
Anoxic reactor	129	43	280	91
Aerobic reactor	249	620	168	254
Settling tank	108	65	89	82
Recycling pumping station	–	67	–	13
Pre-thickner	92	128	10	31
Aerobic digester	–	–	13	10
Anaerobic digester	216	242	–	–
Post-thickners	42	80	–	–
Beltpress	82	190	–	–
Drying beds	–	–	20	–
	918	1,435	620	503
Electr. equip. and hydr. network	–	703[*]	–	335[+]
Accessory works	378[§]	–	180["]	–
Total plant cost	1,296	2,138	800	838
	3,434 ($1.7 \cdot 10^6$ $)		1,638 ($0.8 \cdot 10^6$ $)	

[*] 0.23(918+1,435+703) = 703; [+] 0.23·(620+503+335) = 335; [§] 0.11·(918+1,435+703+378) = 378; ["] 0.11·(620+503+335+180) = 180.

Running costs

Running costs have been broken up as follows: staffing, electric power, operation and maintenance and chemicals (Table 13). In further detail:

- Electric power has been calculated consistently with the value chosen for the dimensioning parameters for each component units, considering also the data reported in specialized literature (4), (5). The specific cost of electric power has been assumed equal to 80 Italian liras/kWh.
- Operation and maintenance costs have been assumed equal to 3% of the electromechanical equipment.

- The alkali consumption to neutralize the acidity released during nitrification, and the phosphorus need for bacteria metabolism resulted equal to 5 kg NaOH [1] /m^3 of wastewater and 63 g P [2] /m^3 of wastewater, respectively. The polyelectrolyte consumption for chemical conditioning of sludge has been taken equal to 3 kg[3]/t of SS.

TABLE 13. RUNNING COSTS (10^6 ITALIAN LIRA/YR)

Item	Slaughter-house wastewater	Coke plant wastewater
Staffing	258	168
Power	280	113
Operation and Maintenance	64	25
Chemicals	14	134
Total	615 ($\simeq 0.5 \cdot 10^6$ $/yr)	440 ($\simeq 0.2$ $/yr)

Overall Costs

The overall costs for treatment plants as outlined above (including amortization and running costs) are reported in Table 14.

Amortization costs were determined on the basis of 15 years for the electromechanical equipment and 30 years for the civil works and on an annual interest on capital of 10%.

The specific costs, per m^3 of wastewater and per kg of incoming pollutant are reported in Table 15.

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[1] 250 Italian liras/kg

[2] 3,400 Italian liras/kg, as H_3PO_4

[3] 7,000 Italian liras/kg

TABLE 14. OVERALL COSTS (10^6 ITALIAN LIRAS/YR)

Item	Slaughter-house wastewater	Coke plant wastewater
Amortization costs:		
civil works	137	85
electromechanical equipment	281	100
total	418	195
Running	615	440
Overall costs	1,033(~$0.5 \cdot 10^6$\$/yr)	635(~$0.3 \cdot 10^6$\$/yr)

TABLE 15. SPECIFIC COSTS

	Slaughter-house	Coke plant
Flow rate	4,000	250
Equivalent inhabitants		
with respect to COD	120,000	14,000
with respect to NH_4-N	100,000	80,000
Total cost (10^6 Italian liras/yr)	1,033 (~$0.5 \cdot 10^6$ \$/yr)	635 (~$0.3 \cdot 10^6$ \$/yr)
Specific costs		
Italian liras/m^3	708 (0.3·\$)	6,960 (3.5·\$)
Italian liras/kg COD	240 (0.1·\$)	1,200 (0.6·\$)
Italian liras/kg NH_4-N	2,360 (1.2·\$)	1,831* (0.9·\$)

* With reference to nitrogen removal equal to 36%

In the case of slaughter-house wastewaters, Table 15 shows how these costs are comparable to the costs related to urban sewage of the same strength and with both BOD and nitrogen removal.

The specific cost referred to coke-owen wastewater is apparently very high but it must be pointed out that conservative figures have been assumed for design calculation, and consequently costs are also over-estimated. Furthermore, treatment costs may be reduced by ammonia stripping before biological treatment; this would be facilitated by high temperature (~25°C), high pH (~9.5) and by favourable free ammonia/combined ammonia ratio (40%) of the raw discharge.

Lastly, it is worth observing that the specific cost of about 7,000 Italian liras per m^3 for wastewater drops to less than 2,000 Italian liras per t of coke produced. Furthermore, if we consider that in steel processing the most highly polluting stage is coke production, the cost is seen to be greatly reduced if it is referred to each unit of steel produced.

UPGRADING CONVENTIONAL DIGESTERS BY FEEDING COMBINED SLUDGE AND CONCENTRATED SOLUBLE WASTEWATERS

In most European countries many conventional digesters for sludge stabilization operate under underloaded conditions. One of the probable reasons for this situation is the overestimation of polluting load for the water works or/and overestimation of sludge production at the design stage.

On the other hand many of the (agro) industrial wastes to be treated are concentrated in organics, poor in nutrients and hence unfit for direct biological treatment.

Mathematical modeling and experiments have shown that the addition of concentrated wastewaters to underloaded once-through concentrational sludge digesters is beneficial because existing works are upgraded by a "free of charge" treatment of the concentrated wastes which could otherwise be treated and/or disposed of in new wastewater plants.

Using mathematical models, I.R.S.A. researchers have investigated the operation of anaerobic digesters as a function of the wastewater composition, namely the ratio between suspended solids and soluble COD.

Although well known in practice, it has been further verified, that the loading rate of a digester fed on suspended solids is relatively low because of limitations on: a) the cell residence times (at low feed suspended solids concentrations) which lead to wash-out of the microorganisms or b) maximum sludge concentration in the reactor. On the other hand, loading rates for digesters fed on prevalently soluble wastewaters can be increased to much higher values

One unforeseen aspect of the modeling study was that it is possible to increase the loading rates of digesters fed on suspended solids if the extra loading is provided as soluble substrate, because the increase of biomass concentration due to the latter substrate does not appreciably alter the total sludge concentration in the reactor.

This functional relationship can easily be seen in figure 15, where the sludge concentrtion in the reactor is plotted vs the sludge residence time for a given voltatile suspended solids loading rate Lsa and for different values of the soluble COD loading rate Lsb.

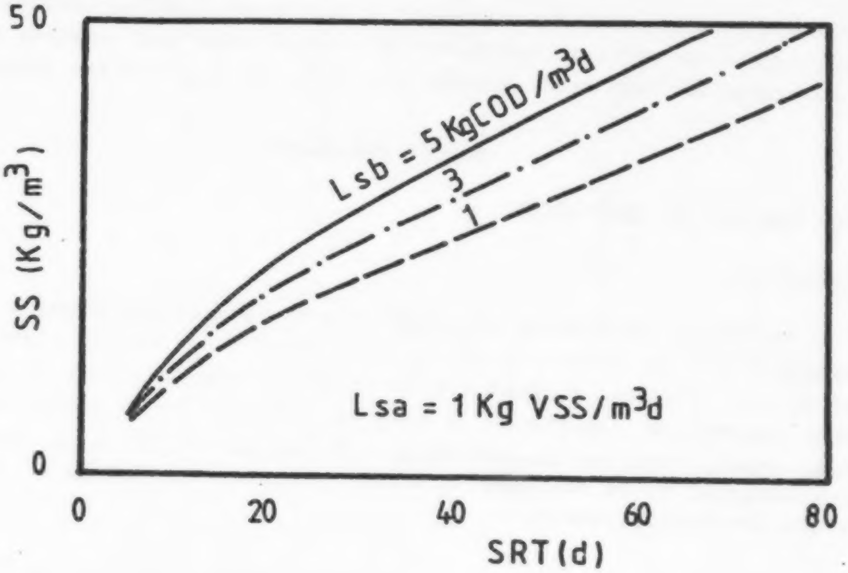

Figure 15. Relationship between solids concentration and solids retention time of fixed loading rates.

Taking into account these considerations and the fact that in Southern Italy there are several oversized sludge digesters, as well as the urgent need to treat or dispose of olive oil mill wastewaters, an experimental research on the combined digestion of sewage sludge and of these highly polluting agroindustrial effluents has been started by I.R.S.A.

Two 25 liter digesters are being tested. The first one is fed on sewage sludge only while the second one is fed on both sewage sludge and olive oil wastewaters. A mixture of primary and secondary sludges from the Bari waterworks is used as suspended solids substrate.

Preliminary results are reported in Table 16.

It is worth noting that specific gas production in reactor II fed on sludge and olive oil effluents increased by about 75% with respect to reactor I without any appreciable negative influence on the anaerobic decomposition of the sludge.

The experiments will be continued on different loading conditions for the two substrates on order to optimize the overall treatment process that will then be tested on real scale plants to verify its application potential.

SLUDGE MANAGEMENT

SLUDGE MECHANICAL DEWATERING

Introduction

In municipal wastewater treatment processes residual sludges amount to approximately 1% by volume of the treated sewage, but in big plants their treatment and handling account for up to 50% of the total operating costs. It is then evident the importance of analysing the different technological alternatives appropriate for transforming a liquid matter (2-3% in concentration) into a material to be disposed of without causing any damage to the receiving body and eventually reused.

Among the sludge treatment processes, mechanical dewatering is considered to be the most delicate and expensive one and is utilized in the majority of the cases. The mechanical dewatering process can take place by filtration or centrifugation; the various technologies available have well marked features that render them capable to meet different requirements and suitable for different utilizations.

Characteristics and problems of sludge mechanical dewatering processes are reviewed in this paper.

TABLE 16. ANAEROBIC DIGESTION OF SEWAGE SLUDGE AND OLIVE OIL WASTEWATERS.
CHARACTERISTICS OF THE FEED REACTOR I (SEWAGE SLUDGE ONLY):
COD = 56 kg/m^3; COD FILT. = 3.6 kg/m^3; SS = 32.5 kg/m^3;
VSS = 25.3 kg/m^3.
REACTOR II (SLUDGE + OLIVE OIL WW): COD = 66.9 kg/m^3;
COD FILT. = 27.6 kg/m^3; SS = 33.5 kg/m^3; VSS = 26 kg/m^3.

	Mean working conditions of reactors			Gas production		Reactor outlet							Efficiency		
	$\frac{kgCOD}{m_R^3 \cdot d}$	$\frac{kgVSS}{m_R^3 \cdot d}$	$i = \frac{c}{d}$	$\frac{m^3}{m_R^3 \cdot d}$	CH_4%	pH	COD unifil. $\frac{kg\ O_2}{m^3}$	COD filt. $\frac{kg\ O_2}{m^3}$	SS $\frac{kg}{m^3}$	VSS $\frac{kg}{m^3}$	TVA $\frac{kg\ AC}{m_R^3}$	alkalinity $\frac{kg\ CaCO_3}{m_R^3}$	COD unfiltered %	SS%	SSV%
Reactor I	2,6	1,2	21	0,51	62	7,6	23	0,6	21,5	14,5	0,2	2,95	59	34	43
ReactorII	4,2	1,2	16	0,89	58	7,3	30	6,5	22,8	15,6	1,45	3,5	55	32	40

Characterization and conditioning

One of the essential conditions to tackle the problem is the knowing of the sludge characteristics.

Many laboratory tests are available for sludge technological characterization; the most often utilized parameters are the solid content (total, suspended, volatile), the density of the dry solids (1.3-2.1 g/cm^3), the pH, the alkalinity (up to 6,000 g/m^3), the SVI (Sludge Volume Index), the specific resistance to filtration (values of 1.10^{12} m/kg at 4.9 N/cm^2 are generally required for good filtration), the compressibility coefficient and the CST (Capillary Suction Time; values of about 10s with ϕ 10 reservoir generally mean good dewaterability).

These parameters, easy to determine, are indirect measurements of fundamental properties (e.g. particle size distribution, Zeta potential, rheological properties) which would be necessary to measure in order to promote a real technical innovation. The influence of these properties on the conditioning and dewatering operation was studied by Campbell et al. (6) and Karr and Keinath (7).

Dewatering is generally preceded by chemical or physical conditioning in order to improve the sludge dewaterability.

In chemical conditioning a destabilization as well as a flocculation can be distinguished. Reagents can be either organic or inorganic, the latter including iron and aluminum salts, lime and a combination of these. Lime, in particular, may be used either as a pre-conditioner (to reduce the alkalinity and thus the reagent consumption), or as a filter aid with an important mass-effect in those cases where cake of a certain thickness are required (as in the case of vacuum-filters). According to Christensen and Style (8) iron salts give better results when used as ferric chloride combined with lime; this treatment, moreover, is suitable (pH$>$12) for sludges to dispose on landfill. Aluminium chlorohydrate, instead, does not require the use of lime since it does not interact with the alkalinity.

Organic reagents consist of polymeric macromolecular compounds which are characterized by monomer type, molecular weight, ionic charge and hydrolysis degree.

The conditioner type and dosage can be assessed in laboratory by general tests (jar-test, specific resistance to filtration, CST, etc.) and specific tests for each type of dewatering technology (filter-leaf, drainability, floc-strength, ecc.) which are in many cases useful to predict full-scale equipment performances. In the following the main specific tests are briefly outlined.

Filter-leaf allows to simulate in laboratory the phases of a vacuum-filter cycle. Methods for predicting beltpress performance have been proposed by Baskerville et al. (9) and Heide et al. (10); the first one consist in a series of drainage tests and one pressure test with a piston press, the second, uses a Modified Filtration Test (MFT) to give an impression of the final dry solid content and of the rate of dewatering. CST measurements at 1,000 rpm stirring with standardized stirrer may be employed to obtain information about the optimal conditioner dosage for centrifugation (Mininni et al. (11); measures of the rheological properties utilizing a modified rheometer (12, 13) give indications similar to that obtainable from the above mentioned tests, while measures of sludge consistency (penetrability) and centrate concentration (14) have not provided satisfactory results with activated sludges. When sludge flocculation is necessary, it is suggested (15) stirring at about 100 rpm for 10-15 minutes followed by stirring at 30 rpm only to avoid sedimentation.

Physical methods include thermal conditioning, freezing and the use of inorganic admixture.

Thermal conditioning involves heating of sludges at a temperature of 180-220 °C for 30-90 minutes. With a mixed sludge it is possible to obtain a high reduction of the specific resistance to filtration operating at 210 °C for 30 minutes (16). After such a process the supernatants or filtrates recycled back to the plant cause a supplementary load of 15-20%; odour problems could also arise. This process has been applied in Europe in big plants equipped with filter-presses or vacuum-filters where it is possible to reach cake concentration up to 50 and 40% respectively.

Conditioning by freezing generally results in a sludge that dewaters extremely well by gravity on subsequent thawing; in this case also the effluent would exert a considerable supplementary load if recycled back to the treatment plant. Energy requirements seem to justify this process only if accomplished by natural means. The use of inorganic substances (ash, diatomaceous earth, etc.) allows to obtain a mixture with improved filtering characteristics and usually less compressible than the sludge alone, but the calorific value is reduced. Ratios of admixtures to sludge solids typically range from 0.5:1.0 to 2:1.

Machine operation

A survey concerning conditioning and dewatering practice in EEC Countries (17) showed that centrifuge (as of now indicated with CF) and filter-presses (FP) are the machines mostly used; belt-presses (BP) are utilized on the average of 20%, while scarse interest is shown for vacuum-filters (VF), except for France.

For the future everything seems to indicate a growing interest towards BP and FP, while the percentage of CF can be expected to keep constant. Similar trends are to be found in N. America where, at present, VF are widely utilized (about 30%).

As far as conditioning is concerned, polyelectrolytes and iron salts, with or without lime, are widely used, while an increasing preference is shown toward the first ones.

Filter-press

Filtration under pressure (50-140 N/cm^2) is the dewatering operation which allows to obtain the highest final solid concentrations. The schematic section of a traditional fixed-plate filter is shown in **Figure 16.**

The operating variables affecting the process are: pressure, filtration time, thickness of chambers and type of cloth. Ferric chloride, with or without lime, and aluminium chlorohydrate are used for conditioning; the use of organic polyelectrolytes has been considered (18) also in view of the savings brought about by the elimination of the flocculation tank, but care must be taken since an overdose would cause cloth blinding. Typical results of filter-pressing are reported in Table 17.

Plate FP operation requires a great deal of labour for filter opening and cleaning; moreover the filter yield is low compared to BP and VF. Experimental tests (15) showed an average yield of 1.5 $kg/m^2.h$ at 147 N/cm^2 and 1.0 at 69 N/cm^2 with an average pressing time of 2-3 h, beyond which filtrate flow rate gets down to very low values (~ 4 l/m^2h).

Different systems have been introduced in order to overcome these inconveniences; the automation of plate movement and cloth washing have made possible a reduction of the costs due to labour, while it has been possible to increase filter yield by the membrane FP (see Figure 16). Parallel tests conducted on chemical sludge conditioned with lime (23) indicated that membrane FP dewater satisfactorily at lower lime dosage and with a greater yield (2.0-3.5 kg/m^2h). Other tests (15) indicated that mixed sludges conditioned at 19.6% of lime and 6.5% of ferric chloride reach

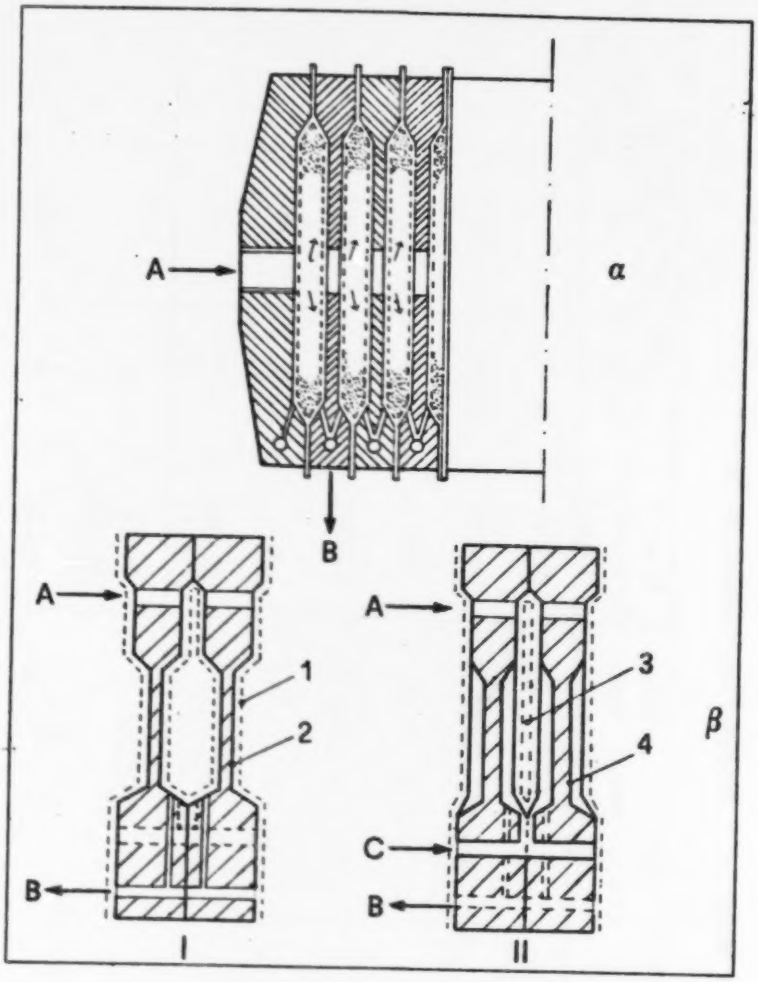

Figure 16. Schematic view of a fixed-plate filter-press (α) and a **membrane** press (β): I filtration phase, II compression phase.
A: feed sludge; B: filtrate; C: pressurized air or water;
1: cloth; 2: soft rubber membrane; 3: cake under compression;
4: moulded rubber body.

TABLE 18. FILTER-PRESS OPERATING DATA

	Sludge type	Input sludge conc. %	Cake conc. %	Time of filtration (min.)	Conditioner dosage		
					FeCl$_3$	CaO	Alum.-Chlor (kgAl$_2$O$_3$/t)
Fixed volume	Raw Primary. U.S.EPA (19)	5.0-10.0	45	90-120	40-60	100-140	
	Digested Prim. Parkhurst et al. (20)	3.8- 4.0	23-37	60-180	40-60	200	
	Raw Prim. + Activ. U.S. EPA (20)	1.0- 6.0	45	150	50-60	100-120	
	Raw Prim. + Activ. White and Baskerville (21)	4.6- 7.6	27-41	290-390	-	-	
	Dig. Prim. + Activ. U.S. EPA (19)	3.5- 5.0	42	-	27	170	
	Dig. Activ. Spinosa and Mininni (22)	4.4- 5.6	37-42	240-360	-	-	
Variable volume				**Yield** (kg/m^{2}h)			
	Raw. Prim. + Activ. U.S. EPA (19)	4.0	40	4.4	50	150	
	Dig. Prim. + Activ. (U.S. EPA (19)	2.5-6.4	36-50	3.0-9.8	40-90	110-290	

a final cake concentration of 38.7%; a yield of 2.4 kg/m^{2}h with 17 minutes of pumping at 69 N/cm^2 and 18 minutes of pressing at 147 N/cm^2 was obtained. The most accepted method of generating design information is to operate a pilot scale plant; being this not always possible, it should be useful to have methods to predict the industrial FP performance. The prediction of pressing time on the basis of the well known equation developed by Jones provides values equal to about 40% of the actual ones. Tests carried out with pilot scale FP have made it possible to develop a new model which allows to correlate the coefficients a and b of the equation expressing the filtrate flux vs time ($\phi = a \cdot t^b$) with pressure, specific resistance and input sludge concentration. Once a, b, the chamber volume, the filtration surface and the dry solids density are known, it is possible to estimate the values of the yield and cake concentration.

A new theory of filter pressing has been developed by Hoyland et al. (24). A small micro-processor programmed with the theory, which is an extension of the classical one of parabolic filtration, can monitor the progress of any filter pressing and, in its later stages, predict the residual pressing time required to produce a cake of a given quality.

Belt-press

BP have been recently introduced into the specific field of sludge dewatering. Dewatering takes place through drainage and compression; moreover, in the final zone, sludge undergoes also a shearing action due to the relative movement of the two belts. A schematic section is reported in Figure 17.

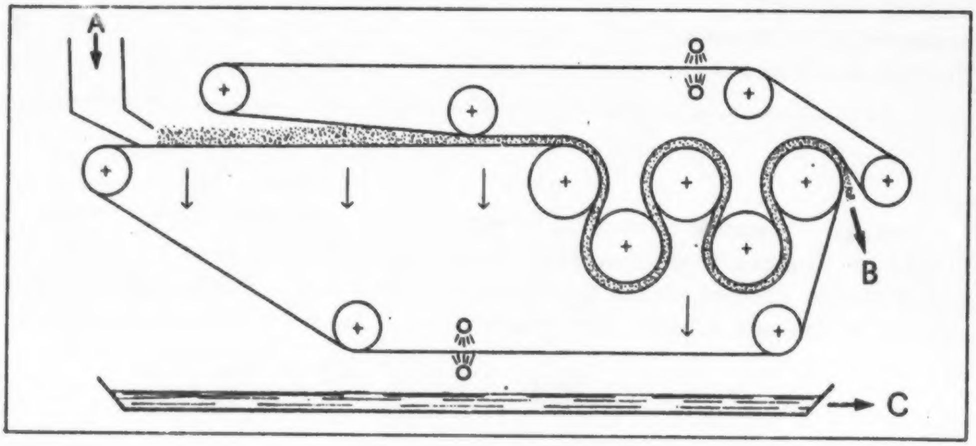

Figure 17. Schematic view of a belt-press.
A: feed sludge; B: dewatered sludge; C: filtrate.

The operating variables affecting the machine performance are: belt speed, the pressure exercised on the belts in the compression zone and the specific sludge flow rate ($m^3/h \cdot m$); this last variable is limited due to the need of avoiding lateral leakage of the sludge. High speed of belts allows to operate at higher capacity values, but a lower final concentration is obtained. In practice, the belts operate at speed ranging between 50 and 100 m/h with a sludge flow rate of 2-5 $m^3/h \cdot m$. For good machine operation, it is advisable to feed the sludge at a concentration not lower than 3-4%. Special care must be taken in belt washing: rinsing water flow rates of 50-200% of that of the sludge at a pressure of 40-60 N/cm^2 are reported by Eckenfeder and Santhaman (25) but higher values (up to 10 $m^3/h \cdot m$) are not uncommon.

Conditioning is carried out by polyelectrolytes with mixing immediately before the drainage zone. Typical results are reported in Table 18 .

TABLE 18. BELTPRESS OPERATING DATA, U.S. EPA (19); IMHOFF, (26)

Sludge type	Input Sludge concentr. (%)	Cake concentr. (%)	Polyelectrol. dosage (kg/t)
Raw Primary	3 - 10	25 - 44	0.5 - 4.5
Raw Activated	0.5 - 4	12 - 32	1.0 - 6.0
Raw Primary + Activated	3 - 6	20 - 35	0.6 - 5.0
Aerobic Digested	1 - 8	12 - 30	0.8 - 5.0
Anaerobically Digested	3 - 9	18 - 34	1.5 - 4.5
Thermal Conditioned	4 - 8	38 - 50	-

Tests carried out (27) with pilot machine (belt width 0.5 m) on sludges from slaughter house wastewater enabled to correlate dewatered sludge concentration C_k (%) with belt speed (m/h), input sludge flow rate Q (m^3/h) and initial concentration C_o (kg/m^3) with the equation:

$$C_k = 76.54\ ^{-0.261}\ Q^{0.269}\ C^{0.024}$$

having a correlation coefficient of 0.92. The input specific flow rate ranged from 1.2 to 3.4 $m^3/h\,m$.

Centrifuge

The type of machine mostly utilized for sludge centrifugation consist of a cylindrical-conical bowl shell with an internal Archimedean screw (the scroll) which revolves at a slightly lower speed. The solid liquid separation takes place like sedimentation, but at g values up to 3000. A centrifuge schematic section and some typical results are reported in Figure 18 and Table 19, respectively.

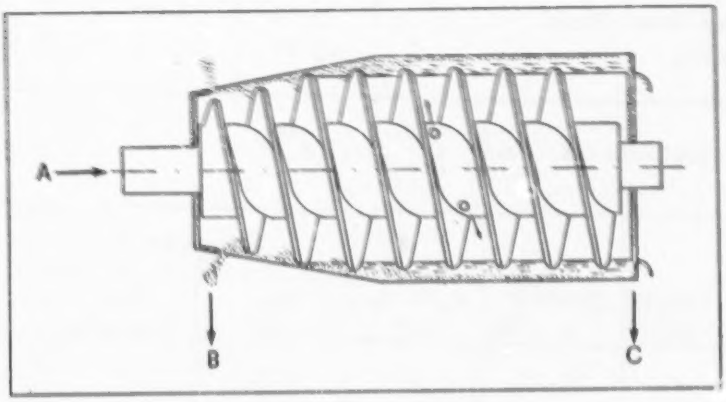

Figure 18. Schematic view of a bowl centrifuge.
A - feed sludge; B - dewatered sludge;
C - centrate

The operating variables which the performance of the machine depends on are: bowl speed, liquid ring height, bowl/conveyor differential speed and input sludge flow rate. Widely accepted indications on the effects of such variables are not found in literature and it is commonly known that for some of them opposite results may also ensue due to values of other variables. For ex. an increase of the differential speed generally causes an increase in solid recovery, but under certain conditions (low liquid ring volume, sludge with a low floc strength) the results might be the opposite due to the high turbulence induced by the scroll which determines the breaking off of the flocs and their resuspension.

TABLE 19. CENTRIFUGE OPERATING DATA, U.S. EPA (19) AND EXPERIMENTAL STATISTICAL CORRELATIONS, MININNI ET AL. (27)

Sludge type	Feed conc. (%)	Cake conc. (%)	Cond. dosage (kg/t)	Solid rec. (%)
Raw Primary	5- 8	25-36	0.5-2.5	90-95
		28-36	0	70-90
Raw Activated	0.5- 3	8-12	5.0-7.5	85-90
Raw Primary + Activated	4- 5	18-25	1.5-3.5	90-95
Digested Primary +	2- 4	15-18	3.5-5.0	90-95
Activated	4- 7	17-21	2.0-4.0	90-95
Thermal Cond. Prim. +	9-14	35-40	0	75-85
Activated	13-15	29-35	0.5-2.0	90-95

Type equations: $Y = ax_1^{b1}\ x_2^{b2}\ \ldots\ldots\ x_d^{bn}$

y	Slude type	Coeff. a	Exponents of x_i = ...				
			$x_i = t_b$ (s)	h_{1r} (mm)	C_{su} (kg/m^3)	ω (rpm)	$\varnothing_s$ (kg/lh)
Dewatered sludge concent.	1	73.75	0.215	0.273	—	—	—
	2	81.79	0.203	0.093	—	—	—
	3	61.25	0.244	0.263	—	—	—
	4	1.22	0.123	- 0.056	0.717	—	—
	5	11.97	0.092	- 0.272	0.084	—	—
	6	0.0122	0.230	0.399	1.745	—	—
Solid recovery	4	93.95	—	—	—	0.313	- 0.946
	5	397.30	—	—	—	0.399	- 1.594
	6	96.78	—	—	—	0.311	- 0.493

t_b: sludge resid. time on the beach; h_{1r}: liquid ring height; C_{su}: conc. after 2 h settling in 1l cylinder; ω : differential speed; $\varnothing_s$: solids input flow rate/liquid ring volume (solids flux); 1: 4,8% Aerob. Dig. Activated; 2: 3.2% Aerob. Dig. Activated with dephospation by $Al_2(SO_4)_3$; 3: 4.5% Aerob. Dig. Activated with dephospatation by $FeSO_4$; 4: 0.7% Aerob. Dig. Activated using pure O_2; 5: 1.5% Aerob. Dig. Activated using pure O_2; 6: 2.1% Aerob. Dig. Activated using air.

To clear up the aspects linked to the solid/liquid separation mechanisms in a centrifuge, pilot scale tests have been carried out with different kinds of sludges(19). From the statistical correlation of the results obtained it was evidenced that the most significant variables influencing the dewatered sludge concentration are the sludge residence time on the beach (which is correlated to the differential speed through the beach length and the scroll pitch) and the liquid ring height. As far as solid recovery is concerned, similar relationships have been looked for, but only with liquid ring heights higher than 11 mm (bowl diameter 151 mm) good correlations were obtained; the differential speed and the flux of solids (referred to liquid ring volume) fed in the centrifuge resulted the most significant variables. Coefficients and exponents experimentally obtained are reported in Table 19. Lower bowl speed values corresponding to 500-800 g bring about advantages in lowering power consumptions, noise, maintenance needs, flocs mechanical stress and, then, conditioner consumption.

It must be kept in mind that, in order to guarantee a good performance and a long life of the machine, coarse or abrasive materials should be avoided, while skilled labour must be employed for maintenance. The advantage of this technology consists above all in the fact that the solid/liquid separation occurs in a place completely isolated from the outside and that the equipment size is limited.

Selection criteria

In treatment plants great care has to be taken in the proper selection of the dewatering machine from which depends the good performance of the subsequent treatments (incineration, composting, etc.) and the easyness and cheapness of disposal.

The most important items to be considered in selecting the dewatering machine are the following:
concentration of the dewatered sludge;
volume of sludge to dewater;
characteristics of the sludge;
investment costs;
operational costs;
treatment of liquids separated during the dewatering operation.

As far as the first point is concerned, the field of application of different technologies is well known: CF allows to obtain a final solid concentration of less than 20% with activated sludges, BP up to 30% and FP of 40%

and even greater if sludge is thermal conditioned. The advantage of a higher solid concentration is easily quantified either if the sludge is subsequently carried to landfill or agricultural soil (volume to be disposed of is reduced) or if it is incinerated (saving of auxiliary fuel). The input sludge flow rate does not prove, in general, to be discriminating toward the various technologies since the potentiality of the dewatering machines available on the market is very wide; in case, the plant has to be equipped with an adequate number of units in parallel with, at least, a spare unit.

Sludge characteristics, either biological or technological, are instead an important factor in the choice of the most suitable equipment. Parameters and tests which is possible to utilize for characterizing sludges and assessing the optimal conditioner dosage have been already mentioned; the evaluation and application of the technological characterization parameters was discussed by Spinosa et al. (29). If the sludge is not well stabilized (volatile solids concentration $> 70\%$ and O_2 up-take > 10 mg/gSSVh) technologies apt to keep the sludge separated from the ambient are to be preferred thus avoiding any trouble to the operators; CF has this requirement.

Another aspect to be taken into account is the area occupied by the dewatering equipment because dimensions are very important in the costs of civil works. In Figure 19, the area required for different machines as a function of the feed sludge flow rate is shown; the advantage of a more compact machine is then made up by a lower final concentration.

Operational costs are heavily affected by labour ones; as already mentioned, FP operation, carried out with traditional machines, requires considerable personnel being the working cycle intermittent, while CF as well implies high personnel costs due to the fact that skilled one is required for maintenance. From this point of view, it is then evident the advantage of BP.

Another important feature of dewatering machines is the efficiency of the solid-liquid separation which is good for FP ($> 95\%$), intermediate for BP (around 95%) while with CF lower values ($< 95\%$) are generally obtained. Since the liquid separated after dewatering is recycled back to the treatment plant, the additional load brought about by this, either in terms of solids or organic matter, is not negligible and could causing the bad operation of the sewage treatment work; from this viewpoint FP has to be preferred.

Design criteria

The designing of dewatering equipment is generally based on empirical criteria derived from experience, rather theoretical developments of general applicability since modelling of filtration and centrifugation processes is

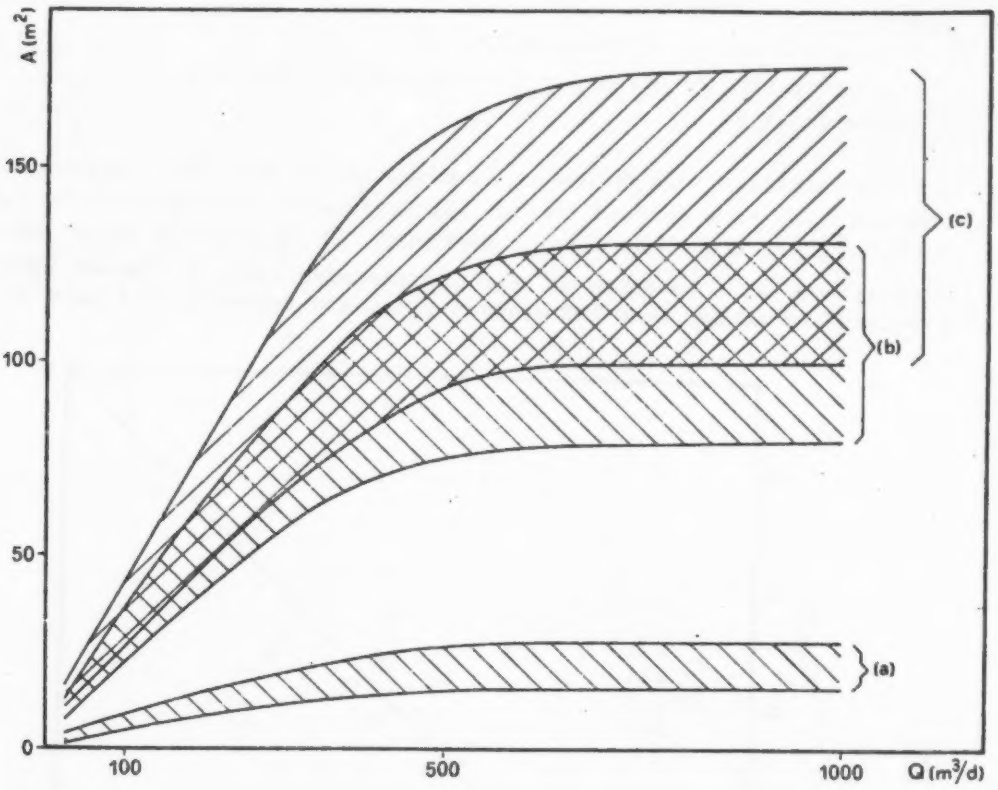

Figure 19. Area occupied by dewatering machines vs wet sludge flow rate (a) centrifuge, (b) belt-press, (c) filter-press
Design data:

m^3/d	20	50	100	500	1000
h oper./d	8	8	8	12	24
n of units	1	1	2	(n + 1 spare)	

very complex and it is not possible to reach functional relationship, solved in finite terms, between the dependent variables (cake concentration, solid removal efficiency) and independent ones (input sludge characterization parameters, operating variables of machines).

For FP designing it is necessary to determine the chamber volume V for treating a daily amount Q of sludge having a concentration C_o:

$$V = \frac{Q\ C_o}{n\ C_k\ \rho_f}$$

where:

n = number of daily filtration cycles;

C_k = concentration required for the cake, weight fraction;

ρ_f = cake density.

To calculate this volume it is essential to know the concentration C_k obtainable after a certain time of filtration; it has therefore to carry out tests on pilot scale. As already mentioned, it is possible to estimate theoretically C_k as a function of time and pressure (20); estimated cake concentrations and actual ones for several cases are compared in Figure 20.

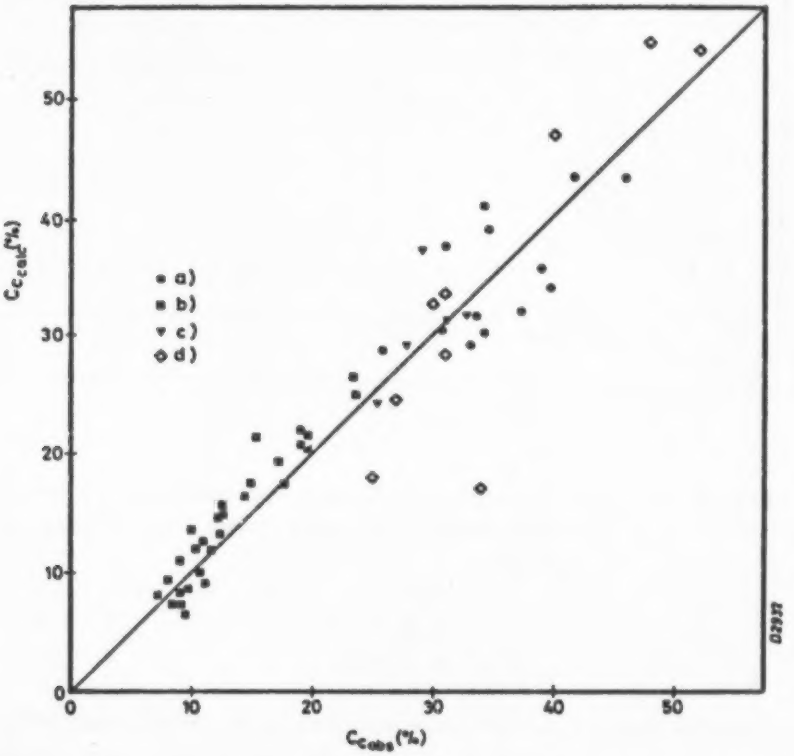

Figure 20. Comparison of calculated cake concentrations and observed ones
a) IRSA-CNR (I) tests; b) IRSA-CNR (I) tests; c) WRC (UK) tests; d) TNO (NL) tests.

As far as BP is concerned one often refers to values taken from experience and that, in particular, are referred to the wet sludge flow rate which can be treated per unit of belt width. Data available in literature

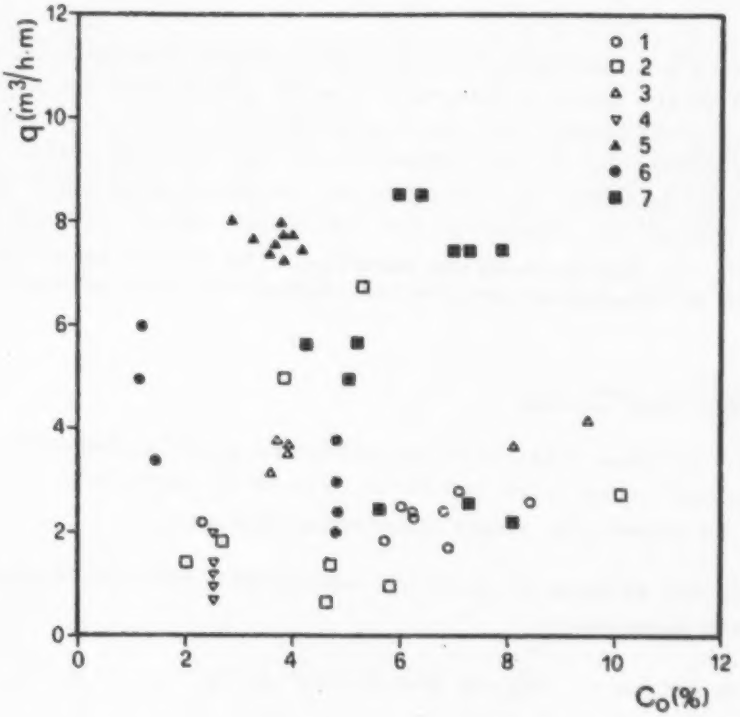

Figure 21. Sludge specific flow rate in belt-pressing vs initial concentration.
1) Imhoff (26); 2) Baskerville et al. (31); 3) Sibamat belt-press tests; 4) Zeper and Pepping (37); 5) Hansen and Budgaard-Hansen (33); 6) Sernagiotto (34); 7) Ecomacchine (35).

(Figure 21) are very discordant thus making difficult to draw general conclusions; it appears however to be appropriate to consider values not higher than 4 $m^3/h{\cdot}m$, but a value between 2 and 3 seems to be on the safe side in a stage project. Due to the wide variation in reported results it would stress the need to conduct pilot-scale tests before specifying the size of BP.

Designing of a CF is generally made by utilizing the theory of Σ (14) being:

$$\frac{Q_1}{\Sigma_1} = \frac{Q_2}{\Sigma_2}$$

where Q is the flow rate and Σ a peculiar characteristic of the equipment representing the area which a gravity sedimentator should have in order to obtain the same solid recovery; subscript 1 is referred to a pilot machine and subscript 2 to an industrial one.

Tests are carried out to determine sludge flow rate Q_1 which can be treated by the pilot CF having a known Σ_1 characteristic with a solid liquid separation efficiency not lower than 80%; the above equation gives then the characteristic Σ_2 of the industrial CF for treating a flow rate Q_2. This procedure, however, only accounts for liquid loading while the movement of solids out of the machine is not considered; the Σ concept (14) allows to estimate the solids handling capacity. The lowest rate (liquid or solid) is then to be considered the limiting factor and must be used for scale-up.

Consumptions and costs

It has been dealt with the different aspects characterizing the various dewatering technologies and which have to be taken into consideration in or order to select the proper dewatering equipment.

In the absence of specific requirements the choice should fall upon the cheapest alternative.

Cost item to consider are the following:

Cost of installation
    electromechanical equipments
    civil works

Cost of operation
    amortization
    electric power
    labour
    maintenance
    chemicals

Costs due to the outputs
    dewatered sludge disposal
    biological treatment of the liquid (filtrate or centrate)
    separated during dewatering.

Just an example, Table 20 shows the costs for dewatering a 4% digested mixed sludge produced in a sewage treatment plant for 100,000 inhabitants; figures considered in the cost analysis are summarized in Table 21. As for calculation of plant costs,up-dated relationships by Beccari et al. (36) have been taken into consideration.

TABLE 20. COST COMPARISON OF DEWATERING SYSTEMS FOR A 100,000 INHAB. PLANT

Cost item	Filterpress. (MLit/y)		Beltpressing (MLit/y)		Centrifuging (MLit/y)	
* Civil work amortization	15.04		9.36		13.18	
** Electrom. eq. amort.	86.89	101.93	117.14	126.50	69.34	82.52
*** Maintenance	14.80		21.59		18.50	
+ Electric power	5.08		7.05		7.20	
++ Operation personnel	18.25		13.69		18.25	
+++ Chemicals	35.37	73.50	44.71	87.04	51.10	95.05
§ Cake disposal	93.98		101.51		144.36	
§§ Biol. treat. of filtrates	10.95	104.93	27.37	128.88	54.75	199.11
Total		208.36		342.42		376.68
(Lit/cap. y)	2.800		3.400		3.800	

*: Interest rate 10%, 25 years; **: Interest rate 10% 12 y for FP, 10 y for BP, 8 y for CF; **: 2.5% of electromech. eq. cost/y for FP, 3% for BP, 5% for CF; +: 80 Lit/kWh; ++: 12.500 Lit/h; +++: $FeCl_3$ 340 Lit/kg, CaO 60 Lit/kg, Polyelectr. 7.000 Lit/kg; §: 17.500 Lit/t wet sludge transported; §§: 600 Lit/kg BOD_5 treated
* 1 $ = 1.400 Lit.

The prevailing energy consumption for FP is due to sludge pumping; consumptions for filter opening and cloth cleaning may be considered equal to 10% of pumping ones. With a pressure of 98 N/cm^2 and a 25% efficiency the energy required is given by:

$$E = 437.6\ Q\ (kWh/y)$$

being Q the wet conditioned sludge flow rate (t/d).

The following equation has been taken into consideration for BP:

$$E = 23600\ F^{0.74}\ (kWh/y)$$

where F is the flow rate (m^3/h) and taking into account a specific flow rate of 3 m^3/hm.

CF consumptions are generally between 1 and 2 kWh/m^3 of treated sludge, being the lower values referred to units at low speed. In calculations a value of 1.7 has been considered as it represents an average value for machines by Pennwalt operating at 3000-4000 rpm.

TABLE 21. ANALYSIS OF DEWATERING EQUIPMENT OPERATION (PLANT FOR 100,000 INHAB.)

	FP	BP	CF
Input dry solids* (kg/d)	5000	5000	5000
Input sludge flow rate (m^3/d)	125	125	125
Conditioners** (kg/d)	985	17.5	20
Conditioner solution (m^3/d)	17.7	17.5	20
Cake concentration (%)	40	30	20
Solid/liquid separation effic. (%)	98	95	90
Cake density (kg/m^3)	1129	1094	1061
Sludge to dispose (kg/d)	14712	15892	22600
Filtrate to treat (kg.BOD_5/d)	50	125	250
Machine design***	1 unit	3 units	1 unit

*: 50 g/cap.d; **: FP: 27 kg$FeCl_3$/tSS + 170 kgCaO/tSS, BP: 3,5 kgPolyel./ /tSS, CF: 4,0 kgPoluel./tSS; ***: 8 h/d, 2 cycles/d for FP, FP chambers volume: 6,51 m^3, BP belt width: 2 m, CF: 18,1 m^3/h.

To calculate costs for operation and maintenance the following values were considered (37):

0.5 h/operational h/machine for FP and CF
0.125 " " " BP

From Table 20 it appears that filter pressing is the most convenient system if the additional costs due to outputs are considered. Otherwise the three machines seem to be equivalent; the total cost of only dewatering is equal to 95-115 lit/kgSS. Dewatered sludge disposal and filtrate biological treatment involve additional costs of 60% for FP and BP and 112% for CF.

Technological progress

The operating problems the various dewatering equipments present forced manufacturers to search for any kind of technical and economical solutions apt to overcome them.

Manufacturers have shown a great interest toward FP and have introduced innovations to extenuate the inconveniences due to non-continuous operation and low yield.

Improvements for BP concern the route of the cloths (with presence of many rollers of different diameter), the drainage phase and the belt washing.

Low speed CF allow, above all, a reduction in power and conditioner consumption. In Equicurrent CF the settled solids are not disturbed by the opposite movement of the liquid and solids are collected throughout the drum length thus bettering compaction and reducing conditioner demand.

Conclusions

What previously discussed can be so summarized:
Filter-press, belt-press and centrifuge are the machines most widely used in sludge mechanical dewatering.

With filter-press the highest cake concentrations are obtained,but operaration is discontinuous and yield low. Belt-press allowsto couple advantages of good cake concentration and continuous operation,but problems can arise in belt washing.

Centrifuge has a lower performance, but the operation is simple and, above all, the liquid-solid separation takes place completely isolated from the out-side.

Filter-pressing is the most convenient system if costs for cake disposal and filtrate or centrate treatment are considered; otherwise the three machines seem to be equivalent.

The main general features of filter-presses, belt-presses and centrifuges are reported in Table (22).

From a general point of view efforts in the future have to be addressed in assessing simple and reliable laboratory methods for selecting conditioner agent type and optimal dosage. Moreover, it seems necessary to go deep into the knowing of a few sludge fundamental properties and of the theoretical modelling of filtration and centrifugation processes if a real technical innovation has to be achieved.

TABLE 22. DEWATERING EQUIPMENT FEATURES

	Flow rate range per unit (m^3/h)	Cake concentrat. (%)	Solid/liquid sep.effic. (%)	Area requirement	Energy demand	Typical advantage
Filter-press	0.1 - 35	30	95	high	low	high solid/liquid separ. efficiency
Belt-press	1.0 - 25	20 - 30	about 95	med - high	medium	low personnel requirem.
Centrifuge	0.5 - 80	20	95	low	med - high	dewatering oper. separated from ambient

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JAPANESE ADVANCES
IN
WASTEWATER TREATMENT

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1. INTRODUCTION

The sewage works in Japan started in 1880 when a sewer of about 2.5 km was constructed in the Kanda area in Tokyo after experiencing epidemics of infectious diseases, such as cholera, several times. Later in 1900, the government enacted the Sewerage Law (old) to provide sewerage systems systematically throughout the country. However, the investment for the sewage works was not big. As of 1940, forty years after the enactment of the law, the sewered area was merely 26,393 ha, and the population served was 5.06 million or about 8 percent of the total population at that time. Main purposes for the sewage works at that time, were to prevent from flooding in urban areas and to maintain the cleanliness in cities. Due to the increase in population in cities, the amount of wastewater discharged increased, and therefore, it became necessary to construct wastewater treatment plants in big cities from a viewpoint of public health. In this connection, the secondary treatment of sewage in major cities started rather early. The first wastewater treatment plant with tricklig filters was constructed in Tokyo City in 1922. In succession, two plants using the activated sludge process were constructed in Nagoya City in 1930. In 1940, 12 plants with secondary treatment were in service.

The economic growth, particularly the growth of heavy industries, and the concentration of population in big cities in 1950's were quite marked posing the serious problem of river and coastal water pollution especially around big cities. Water pollution became more serious during late 1950's and 1960's, which was typically represented by two tragic events, namely "Minamata" disease (an organomercury poisoning) and "Itai-Itai" disease (a cadmium poisoning). To cope with these situations, the relevant laws for the water pollution control were enacted late in 1960's. The Basic Law for Environmental Pollution Control was established in 1967; through this enactment the environmental water quality standards relating to human health and living environment were set up as shown in Tables 1.1 and 1.2, respectively. In addition, such concrete steps as the preparation of a public hazard prevention plan were established one after another. Also, in 1970, the water pollution control law was revised to strengthen the effluent regulation. Through this amendment, uniform effluent standards were established by the national government as a minimum requirement, and also, it was guaranteed that the prefectural governments could establish more stringent standards by their ordinances depending on the conditions of each water body. The national uniform standards are given in Table 1.3. At present, all of the prefectural governments have established their own ordinances which enforce standards more stringent than the national uniform ones. As a typical example of the overlay standard, the effluent standards of Chiba prefecture are also shown in Table 1.3. The prefectural governments are also authorized to set effluent standards relating to pollutants which are not regulated by the national uniform standards. The effluent standards for phosphorus and nitrogen were established by the Shiga Prefecture for the Lake Biwa basin in 1979, which is shown in Table 1.4 is an example of the standards of this kind.

Regarding to the pretreatment standards which are applied to the industries discharging their wastewater into a public sewerage system, a sewerage authority under the Sewerage Law can establish the same standards as those applied to the industries discharging their wastewater directly into the public bodies of water under the Water Pollution Control Law as far as the toxic substances are concerned.

Table 1.1 Environmental water quality standards relating to human health (Dec. 28, 1971)

Item	Standard values[1]
Cadmium	0.01 ppm or less
Cyanide	Not detectable
Organic phosphorus[2]	Not detectable
Lead	0.1 ppm or less
Chromium (sexivalent)	0.05 ppm or less
Arsenic	0.05 ppm or less
Total mercury	0.0005 ppm or less
Alkyl mercury	Not detectable
PCB	Not detectable

Notes: 1. Maximum values. But with regard to total mercury, standard value is based on the yearly average value.
2. Organic phosphorus includes parathion, methyl parathion, methyl demeton and E.P.N.

The sewage works actually restarted from the enactment of the new Sewerage Law in 1958. Since the role of sewage works in the field of water pollution control had been widely recognized, the clause, "to contribute to the preservation of water quality in public water bodies", was added to the purpose of the sewage works defined by the law through its amendment in 1970. The construction of sewerage facilities has further been promoted by the amendment. Figure 1.1 shows trends in the investment in the sewage works in the past. From this figure, it is seen that the investment in sewage works increased at a far higher rate when compared with that of the GNP or the government fixed capital formation. Although the investment after fiscal year 1982 declined a little reflecting the financial condition of the Japanese government, the investment in fiscal year 1983 remained 1.6 billion yen, which accounted for 0.57% of the GNP. As the result this rush investment in sewerage construction, population served has recently increased fairly rapidly in big cities for instances, 80% in Tokyo, 99% in Osaka, 87% in Nagoya, 72% in Kyoto, 56% in Yokohama and 46% in Hiroshima in 1984, although its nationwide ratio still remains rather low at 33%. Therefore, the situation of water pollution has improved considerably. The ratio of compliance to environmental water quality standards has become steadily better as shown in Fig. 1.2. The problem relating to toxic substances is discussed in Chapter 2.

There still remains, however, a lot of problems in the field of sewage works, such as sludge treatment and disposal, advanced wastewater treatment, energy conservation and proper wastewater treatment process for smaller scale facilities. For preventing eutrophication of lakes, environmental water quality standards for phosphorous and nitrogen were set up in 1982 as shown in Table 1.5. At present, the standards are being individually set for lakes throughout the country. Some wastewater treatment plants which discharge effluent to this kind of lakes have already started treatment to remove phosphorous and nitrogen from their effluent. In this paper the recent progress in wastewater treatment technology in Japan will be summarized.

Table 1.2 Water quality standards relating to the living environment (rivers, lakes, coastal waters)

Coastal waters

Category	Use	Standard values[a]				
		pH	Chemical oxygen demand (COD^{Mn})	Dissolved oxgen (DO)	Number of coliform groups[d]	N-hexane extracts
A	Fishery class 1[e]; bathing; conservation of natural environment, and uses listed in B–C	7.8–8.3	2 mg/ℓ or less	7.5 mg/ℓ or more	1000 MPN/100 mℓ or less	Not detectable
B	Fishery class 2,[f] industrial water, and uses listed in C	7.8–8.3	3 mg/ℓ or less	5 mg/ℓ or more	-	Not detectable
C	Conservation of environment	7.0–8.3	8 mg/ℓ or less	2 mg/ℓ or more	-	-

[a] The standard values are based on the daily average values. (The same applies to standard values for lakes and coastal waters.)

[b] At the inlet of agricultural water, pH shall be between 6.0 and 7.5 and dissolved oxygen shall not be less than 5 mg/ℓ. (The same applies to standard values for lakes.)

[c] With regard to fisheries, classes 1, 2, and 3, the standard values for suspended solids shall not be applicable for the time being.

[d] With regard to the quality of fisheries, class 1 for planting oysters, the number of coliform groups shall be less than 70 MPN/100 ml.

[e] Fishery class 1: Aquatic life such as red sea-bream, yellow tail, seaweed.

[f] Fishery class 2: Aquatic life such as gray mullet, laver, etc.

Notes: Conservation of natural environment: of scenic spots and other natural resources.

Water supply class 1:
Water that requires simple cleaning treatment such as filtration.
Water supply class 2:
Water that requires normal cleaning treatment such as sedimentation and filtration.
Water supply class 3:
Water that requires highly sophisticated cleaning treatment including pretreatment.
Fishery class 1:
For fish such as trout and bull trout in oligosaprobic waters, and those of fisheries class 2 and class 3.
Fishery class 2:
For fish such as fish of the salmon family and sweetfish in oligosaprobic waters and those of fisheries class 3.
Fishery class 3:
For fish such as carp and silver carp in β-mesosaprobic water.
Industrial water class 1:
Water should be given normal cleaning treatment such as sedimentation.
Industrial water class 2:
Water should be given sophisticated treatment by chemicals.
Industrial water class 3:
Water should be given special cleaning treatment.
Conservation of environment:
Up to the limits at which no nuisance is caused to people in daily life (including walking by the riverside, shore, and so on).

Table 1.2 Water quality standards relating to the living environment (rivers, lakes, coastal waters) (Cont'd)

Lakes (Natural lakes, reservoirs, marshes, and artificial lakes or more than 1 x 16^6 m^3 water)

Category	Use	Standard values[a]				
		pH	Chemical oxygen demand (COD^{Mn})	Suspended solids (SS)	Dissolved oxygen (DO)	Number of coliform groups
AA	Water supply class 1; fishery class 1; conservation of natural environment, and uses listed in A-C	6.5-8.5	1 mg/ℓ or less	1 mg/ℓ or less	7.5 mg/ℓ or more	500 MPN/100 ℓ or less
A	Water supply classes 2 and 3; fishery class 2; bathing, and uses listed in B-C	6.5-8.5	3 mg/ℓ or less	5 mg/ℓ or less	7.5 mg/ℓ or more	1000 MPN/100 mℓ or less
B	Fishery class 3; industrial water class 1; agricultural water,[b] and uses listed in C	6.5-8.5	5 mg/ℓ or less	15 mg/ℓ or less	5 mg/ℓ or more	-
C	Industrial water class 2; conservation of environment	6.0-8.5	8 mg/ℓ or less	Floating matter such as garbage should not be visible	2 mg/ℓ or more	-

Rivers

Category	Use	Standard values[a]				
		pH	Biochemical oxygen demand (BOD)	Suspended solids (SS)	Dissolved oxygen (DO)	Number of coliform groups
AA	Water supply class 1; conservation of natural environment, and uses listed in A-E	6.5-8.5	1 mg/ℓ or less	25 mg/ℓ or less	7.5 mg/ℓ or more	50 MPN/100 ℓ or less
A	Water supply class 2; fishery, class 1; bathing and uses listed in B-E	6.5-8.5	2 mg/ℓ or less	25 mg/ℓ or less	7.5 mg/ℓ or more	1000 MPN/100 mℓ or less
B	Water supply class 3; fishery class 2, and uses listed in C-E	6.5-8.5	3 mg/ℓ or less	25 mg/ℓ or less	5 mg/ℓ or more	5000 MPN/100 mℓ or less
C	Fishery class 3; industrial water class 1, and uses listed in D-E	6.5-8.5	5 mg/ℓ or less	50 mg/ℓ or less	5 mg/ℓ or more	-
D	Industrial water class 2; agricultural water,[b] and uses listed in E	6.0-8.5	8 mg/ℓ or less	100 mg/ℓ or less	2 mg/ℓ or more	-
E	Industrial water class 3; conservation of environment	6.0-8.5	10 mg/ℓ or less	Floating matter such as garbage should not be visible.	2 mg/ℓ or more	-

Table 1.3 Effluent standards

Substances related to human health

(Unit mg/ℓ)

Toxic substances	National uniform standards	Overlay standards of Chiba Pref.
Cadmium and its compounds	0.1	0.01
Cyanide compounds	1	Not detectable [a]
Organic phosphorus compounds (parathion, methyl parathion, methyl demeton and EPN only)	1	Not detectable [a]
Lead and its compounds	1	0.1
Chromium (VI) compounds	0.5	0.05
Arsenic and its compounds	0.5	0.05
Total mercury	0.005	0.0005
Alkyl mercury compounds	Not detectable [a]	Not detectable [a]
PCB	0.003	Not detectable [a]

Items related to living environment

Item	National uniform standards	Overlay standards of Chiba Pref.
pH	5.8-8.6 for effluent discharged into public water areas other than coastal waters, and 5.0-9.0 for effluent discharged into coastal waters	5.8-8.6 for effluent discharged into public water areas other than coastal waters, and 5.0-9.0 for effluent discharged into coastal waters
BOD, COD^{Mn}	160 mg/ℓ (daily average 120 mg/ℓ)	25 mg/ℓ
SS	200 mg/ℓ (daily average 150 mg/ℓ)	50 mg/ℓ
N-hexane extracts	5 mg/ℓ (mineral oil) 30 mg/ℓ (animal and vegetable fats)	3 mg/ℓ (mineral oil) 10 mg/ℓ (animal and vegitable fats)
Phenols	5 mg/ℓ	0.5 mg/ℓ
Copper	3 mg/ℓ	1 mg/ℓ
Zinc	5 mg/ℓ	3 mg/ℓ
Dissolved iron	10 mg/ℓ	5 mg/ℓ
Dissolved manganese	10 mg/ℓ	5 mg/ℓ
Chromium	2 mg/ℓ	1 mg/ℓ
Fluorine	15 mg/ℓ	10 mg/ℓ
No. of coliform groups (per cc)	3000 (daily average)	3000 (daily average)

[a] By the term "not detectable" is meant that substance is below the level detectable by the method designated by the Law or the ordinance.

Note: The effluent standards in this table are applicable to effluents from industrial plants or other business places whose volume of effluents per day is 50 m^3 or more. The effluent standards for BOD are applied to public waters other than coastal waters and lakes, whereas the standards for COD^{Mn} are applied only to effluents discharged into coastal waters and lakes.
Overlay standards shown in this Table as examples are those provided for by the ordinance of Chiba Prefecture and are applied for food industry with a discharge of 500 m^3/day or more.

Table 1.4 Effluent standards relating to phosphorus and nitrogen provided for by the ordinance of Shiga Prefecture for controlling eutrophication of Lake Biwa

(Unit: mg/ℓ)

Parameter	New or existing facility	Discharge	Food industry	Textile industry	Chimical industry (excluding gelatin industry)	Gelatin manufacturing industry	Other manufacturing industries	Sewage treatment plant	Collective night soil treatment plant	Night soil treatment plant	Other businesses
Total nitrogen	Existing	m^3/day						Average	Average	Average	
		30 - 50	25	15	12	20	15	20	20	(20)	30
		50 - 1,000	20	12	10	15	12	20	20	(20)	25
		more than 1,000	15	10	8	12	8	20	20	(20)	20
	New							Provisional			
		30 - 50	20	12	10	15	12	20	10	(20)	25
		50 - 1,000	12	8	8	10	8	20	10	(20)	20
		more than 1,000	10	8	8	10	8	20	10	(20)	20
Total phosphorus	Existing	m^3/day						Average	Average	Average	
		30 - 50	4	2	2	2	1.5	1	2	(5)	5
		50 - 1,000	3	1.5	1.5	1.5	1.2	1	2	(5)	5
		more than 1,000	2	1	1	1	0.8	1	2	(5)	3
	New	30 - 50	2	1.2	1.2	1.2	1	0.5	1	(5)	4
		50 - 1,000	1.5	0.8	0.8	0.8	0.6	0.5	1	(5)	3
		more than 1,000	1	0.5	0.5	0.5	0.5	0.5	1	(5)	2

Remarks: 1. Values for sewage treatment plants, collective night soil treatment plants and night soil treatment facilities are daily average. Others are maximum.
2. Standards for night soil treatment facilities shall not be enforced for the time being.
3. Nitrogen standard for sewage treatment plants shall be a provisional one.

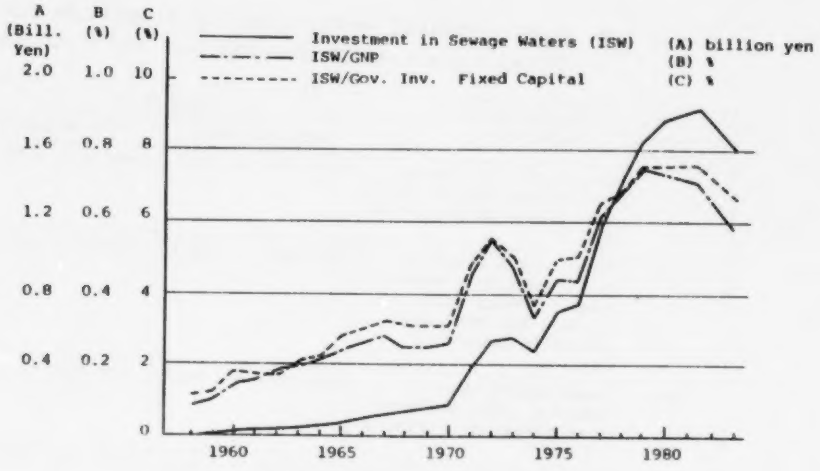
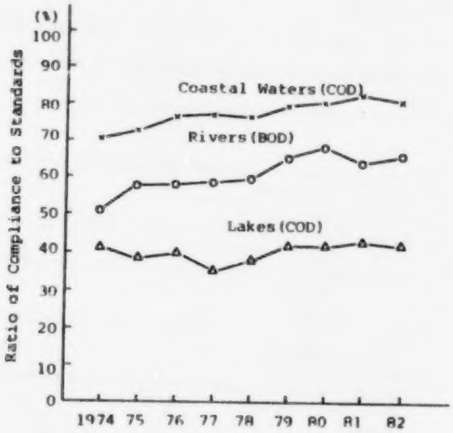


Fig. 1.1 Investment in sewage works in the past



Remarks: 1.

$$\text{Rate of compliance} = \frac{\text{Number of water bodies where environmental standards are met}}{\text{Number of water bodies where environmental standards are set}} \times 100\ (\%)$$

2. For the environmental water quality standards, 6 categories are set for rivers, 4 categories for lakes, and 3 categories for coastal waters according to the water uses.

Fig. 1.2 Ratio of compliance to environmental water quality standards

Table 1.5 Environmental water quality standards for lakes relating to phosphorous and nitrogen

Item / Category	Applicability to water use	Standards	
		Total nitrogen	Total phosphorous
I	Conservation of natural environment and for water uses listed in Categories II - V	Less than 0.1 mg/ℓ	Less than 0.005 mg/ℓ
II	Water supply classes 1, 2, and 3 (excluding special ones), Fishery class 1, Bathing and water uses listed in Categories III - V	Less than 0.2 mg/ℓ	Less than 0.01 mg/ℓ
III	Water supply class 3 (special ones) and water uses listed in Categories IV and V	Less than 0.4 mg/ℓ	Less than 0.03 mg/ℓ
IV	Fishery class 2 and water uses listed in category	Less than 0.6 mg/ℓ	Less than 0.05 mg/ℓ
V	Fishery class 3, Industrial water, Agricultural water, and Conservation of environment	Less than 1 mg/ℓ	Less than 0.1 mg/ℓ

Remarks: 1. Standards are based on the annual average values.

2. The standard of total phosphorous is not applied to agricultural water.

Notes: 1. Conservation of natural environment: of scenic spots and other natural resources.

2. Water supply class 1:
Water that requires purifying operation such as filtration.
Water supply class 2:
Water that requires normal purifying operation such as sedimentation and filtration.
Water supply class 3:
Water that requires highly sophisticated purifying operation including pretreatment.

3. Fishery class 1:
Water for fish, such as salmon and sweetfish, etc., and those of fishery classes 2 and 3.
Fishery class 2:
Water for fish, such as pond smelt, etc., and those of fishery class 3.
Fishery class 3:
Water for fish, such as carp and crucian.

4. Conservation of environmental conditions:
Up to the limits at which no nuisance is caused to people in daily life (including walking by the shore and so on).

2. MICROPOLLUTANT (TOXICS) CONTROL IN JAPAN

2.1 Outline of Toxics Control System in Japan

The fundamental law for environmental pollution control in Japan is the Basic Law for Environmental Pollution Control which was established in 1970. The legal system for water quality management based on this law is shown in Fig. 2.1.

In order to maintain better environmental quality, particularly relating to toxic substances, a comprehensive policy should be adopted taking local conditions into consideration. The major countermeasures against toxic substances pollution would be classified as follows:

(1) effluent discharge regulation
(2) construction of wastewater treatment facility
(3) regulation on production and use of particular substances
(4) stream flow augmentation and removal of contaminated sediments, and
(5) others such as monitoring, development of treatment technology, tax or financial system, compensation for damage and so forth

The effluent discharge regulation is done based on the water Pollution Control Law. It is difficult, however, in most cases to control pollutant discharge from small scale industries or household individually. Therefore, the construction of sewerage systems is quite important for protecting public water bodies. It sometimes is effective to introduce dilution water or to dredge contaminated sediments, particularly for polluted rivers in urban areas.

Some of chemical compounds might have properties affecting seriously on human health or on the environment. In order to prevent potential hazards of this kind, new and existing chemical substances are being examined by the system provided by the Chemical Substances Screening and Control Law.

2.2 Toxics Control by Effluent Standards

2.2.1 Compliance of toxic substance with environmental water quality standards

As described in Chapter 1, environmental water quality standards relating to toxic substances are set for nine items: cadmium, cyanide, organic phosphorous, lead, chromium (hexavalent), arsenic, total mercury, alkyl mercury, and PCBs. (Refer to Table 1.1) Most of these values are identical to those for drinking water supply. For mercury and PCB, however, their standard values were determined taking into consideration damage caused by their accumulation/concentration in fish and shellfish.

According to measurement results for public water bodies throughout Japan in 1983 for these substances, of the total number of samples 179,000 taken at 5,239 stations throughout the country, the percentage of samples exceeding the environmental standards was only 0.04% as shown in Table 2.1. Mercury, organic phosphorous, and PCB were not detected at any sampling stations. No sampling stations recorded average annual concentrations of total mercury in excess of the environmental quality standard.

Table 2.1 Ratio of toxic substances exceeding environmental standards

Item	Year	Number of samples (A)	Number of samples exceeding environmental standards (B)	Ratio (%) (B)/(A)
Cadmium	1971	15,944	114	0.72
	1983	27,881	28	0.10
Cyanide	1971	12,453	142	0.14
	1983	23,500	8	0.03
Organic phosphorus	1971	5,116	11	0.22
	1983	8,529	0	0
Lead	1971	14,515	202	1.39
	1983	27,962	7	0.03
Hexavalent chromium	1971	11,532	15	0.13
	1983	24,167	3	0.01
Arsenic	1971	11,530	48	0.42
	1983	25,488	12	0.05
Total mercury	1971	12,364	32	0.26
		Number of samples	Number of samples exceeding 0.0005 mg/ℓ	Number of points exceeding environmental standard value
	1983	29,978	13	0
		Number of samples (A)	Number of samples exceeding environmental standards (B)	Ratio (%) (B)/(A)
Alkyl mercury	1971	5,624	0	0
	1983	7,850	0	0
PCBs	1975	3,130	12	0.38
	1983	4,086	0	0
Total	1971	89,074	504	0.57
	1983	149,463	58	0.04

Fig. 2.2 shows trends in the ratio of non-compliance with the environmental standard for each toxic substance. As shown in this figure, the water quality in public water bodies has been remarkably improved over these 15 years as the result of the efforts in water pollution control.

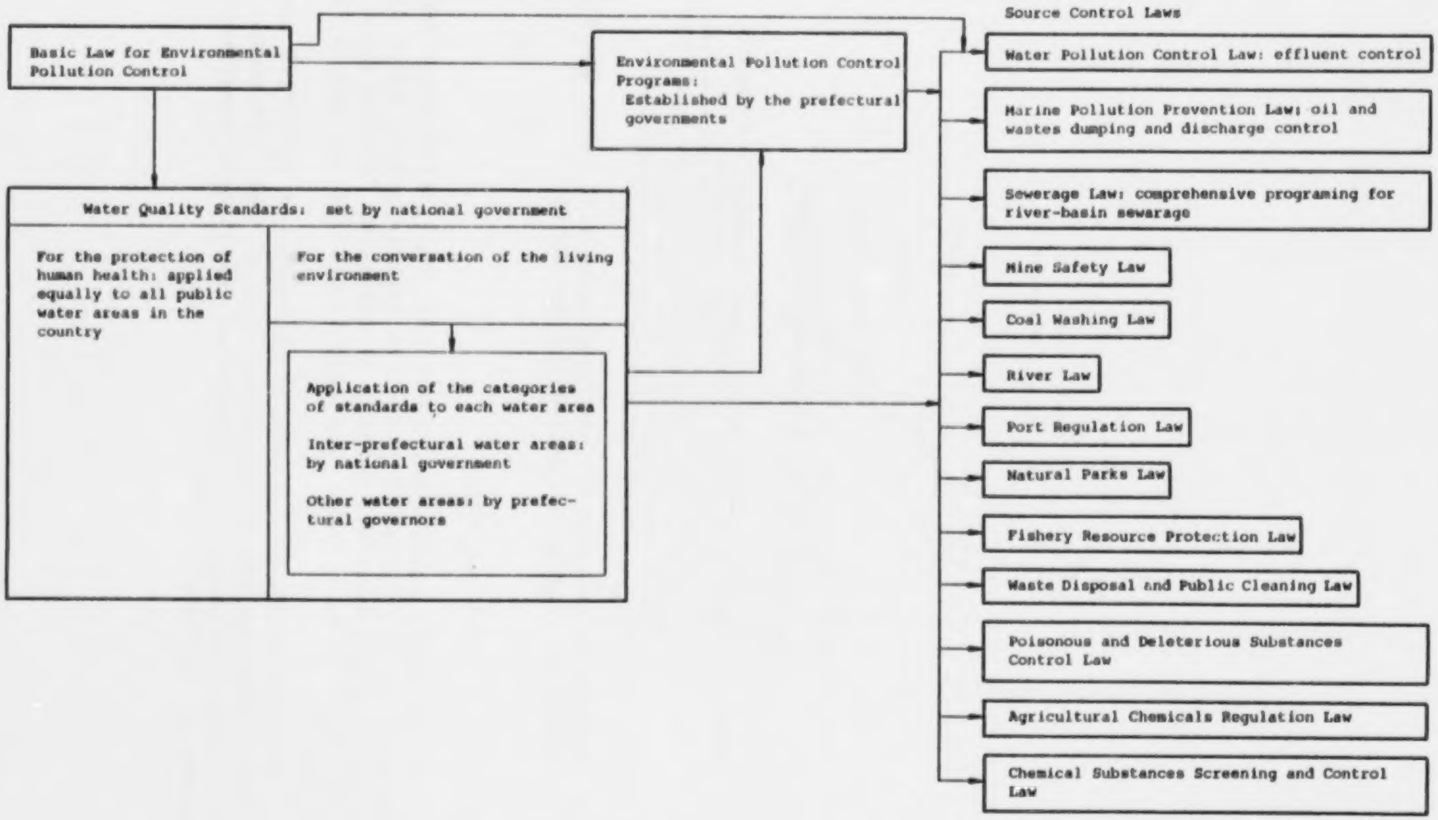
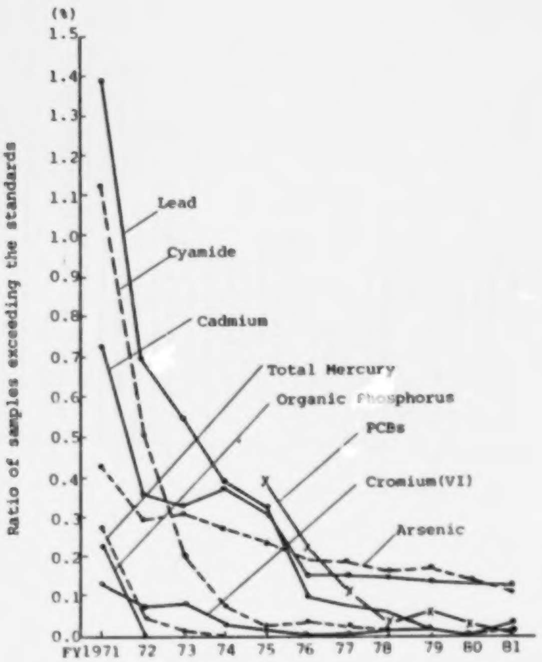

Basic Law for Environmental Pollution Control
Environmental Pollution Control Programs: Established by the prefectural governments
Water Quality Standards: set by national government
For the protection of human health: applied equally to all public water areas in the country
For the conversation of the living environment
Application of the categories of standards to each water area
Inter-prefectural water areas: by national government
Other water areas: by prefectural governors
Source Control Laws
Water Pollution Control Law: effluent control
Marine Pollution Prevention Law: oil and wastes dumping and discharge control
Sewerage Law: comprehensive programing for river-basin sewarage
Mine Safety Law
Coal Washing Law
River Law
Port Regulation Law
Natural Parks Law
Fishery Resource Protection Law
Waste Disposal and Public Cleaning Law
Poisonous and Deleterious Substances Control Law
Agricultural Chemicals Regulation Law
Chemical Substances Screening and Control Law

Fig. 2.1 Legal system for water quality management



Remarks: 1. Standards for alkyl mercury, organic phosphorus, and PCBs were set at N.D. from 1971, 1972 and 1975, respectively.

2. For total mercury, annual average at each point was determined as the base for evaluation since September, 1974. No locations was found to exceed the standard value since then.

3. The total was obtained for 8 substances excluding mercury.

Fig. 2.2 Changes in the rate of non-compliance with water quality standards (ratio of samples exceeding the standards)

2.2.2 Sources of water pollution

In the Water Pollution Control Law, facilities which discharge toxic substances or facilities of more than certain scale, which discharge non-toxic pollutants, are defined as specified facilities, and the factories which have these specified facilities are made a subject for control.

As shown in Table 2.2, the total number of specified factories as of 31 March 1985 was 278,861 in Japan. Out of them, the number of factories where toxic substances were discharged was 13,161, constituting 4.7 percent of the total number.

Table 2.2 Number of specified factories

	Discharge more than 50 m^3/day	Discharge less than 50 m^3/day	
(A) Fiscal Year 1984	30,006 (3,820)	248,855 (9,341)	278,861 (13,161)
(B) Fiscal Year 1983	29,913 (3,782)	247,227 (8,652)	277,140 (12,434)
Rate of Increase (A)/(B)	1.01 (1.01)	1.01 (1.08)	1.03 (1.06)

Note: Numbers in parenthesis are factories which discharge toxic substances.

The major types of factories which discharge toxic substances are given in Table 2.3.

Table 2.3 Types of facilities discharging major toxic substances

(1983)

	Kind of business or name of facilities	Number of facilities	Major toxic substances being discharged
1	Natural science institute and laboratory	2,832	CN, Alkyl mercury, organic phosphorus, Cd, Pb, Cr^{6+}, As, Hg
2	Electroplating facilities	2,226	CN, Cd, Pb, Cr^{6+}
3	Acid and alkali treatment facilities of metal surface	1,554	Cd, Pb, Cr^{6+}, As
4	Cement manufacturing	776	
5	Ready mixed concrete manufacturing	672	
6	Glass manufacturing	633	CN, Cd, Pb, As
7	Metallic goods manufacturing and machinery industry	600	CN, Cd, Pb, Cr^{6+}, As, Hg
8	Wastes treatment plant	508	
9	Photo developing	459	CN, Cd, Pb, Hg
10	Automatical washing facilities of car	328	Hg

2.2.3 Control of factories

The responsible person for controlling and monitoring factories is the governor of each prefecture. When a factory installs a specified facility or changes the structure of his specified facility, he must notify it to the prefectural governor. When the governor judges that the effluent from the specified facility is unlikely to be compliant with the standards, he can order an alternation for the plan in installment or structure within 60 days from acceptance of the notice. In 1983, the number of notice reporting an installment of a specified facility was 9,493 (cases) (including those discharging non-toxic pollutants). While, the number of notice reporting an alternation in the structure was 5,146 (cases). In neither of these cases was change in plan asked by the governor.

When a prefectural governor judges that effluent from an existing specified facility does not comply with the effluent standards, he can order an improvement in the structure or operation of the specified facility, or the wastewater treatment method within a specified period; or he can order to temporarily discontinue the use of the specified facility or the discharge of effluent. The number or factories ordered to improve their structure or operation of the specified facilities, or the wastewater treatment method totalled 304 (cases) in 1983. While, the number of specified facilities ordered to temporarily discontinue use of those specified facilities or the effluent discharge totalled 14 (cases) in the same year. In addition, those subjected to the administrative guidance for improvement, although not ordered to improve, totalled 17,000 (cases).

The law provides that if dischargers violate the standards, they are sentenced to a prison term not exceeding 6 months, or punished with a fine not exceeding 300 thousands yen. The number of cases violating the effluent standards totalled 201 in 1983. Two cases resulted from regular inspection, 19 cases resulted from reports by local inhabitants, and 180 cases resulted from police or Maritime Safely Agency action. The parameters that were violated are shown in Table 2.4, and the types of industries which violated the standards are shown in Table 2.5. Of those who were arrested until 1982 and sentenced within 1982, nobody was given a prison term, however, 114 persons were fined.

The prefectural governor can send his personnel to enter a specified factory for inspection of the structure, the wastewater treatment facilities, and relevant documents of the factory. Inspections made in 1983 were 88,155 cases during the day and 2,335 cases at night, totalling 90,470 cases.

2.2.4 Measures taken at sources

To prevent pollution from public water bodies, it is necessary for the relevant authorities to take proper measures to enforce the standards and to monitor the discharge from working places where use any toxic substances. However, it is essential as well that each pollutor makes his effort to curb the discharge of pollutants as far as possible. It is the first step for a discharger in reducing effluent toxicity to change the manufacturing process if there is a better process or to reduce or change chemicals and materials used, or to recover wastes. To treat the effuent is the second step to comply with the effluent standards.

The treatment method varies according to the toxic substance to be treated. Table 2.6 shows typical treatment methods for toxic substances used in Japan.

Table 2.4 Violation of effluent standards

(1983)

	Parameters violated	Number of violations
1	Suspended solid	102
2	BOD	80
3	pH	70
4	COD	32
5	Hexavalent chromium	23
6	Cyanide	10
7	Number of coliform groups	8
8	Normalhexame extracts	7
9	Copper	6
10	Zinc	5

Table 2.5 Types of facilities violating toxic substance discharge standards

(1983)

Item	Kind of violating facilities	Number of violations
Hexavalent chromium	1 Electroplating facility	14
	2 Cement manufacturing	4
	3 Acid and alkali treatment facilities of metal surface	3
	4 Metallic goods manufacturing and machinery industry	1
	5 Textile industry	1
Cyanide	1 Electroplating facility	8
	2 Acid and alkali treatment facilities of metal surface	5
	3 Metallic goods manufacturing and machinery industry	1
Lead	1 Electroplating facility	2
	2 Raw pottery materials manufacturing	2
	3 Glass manufacturing	1
Cadmium	1 Industrial waste treatment plant	1

Table 2.6 Typical treatment methods for toxic substances

Item	Treatment method
Cyanide	Alkaline chlorination Electrolytic oxidation Complex ion method
Heavy metals (Cd, Pb, Cu, Zn, Fe, Mn, Cr^{3+})	Chemical precipitation Ion exchange
Hexavalent chromium	Reduction and neutralization Ion exchange
Mercury	Sulfide precipitation Carbon absorption Chelate resin adsorption
Arsenic	Hydroxide co-precipitation
PCB	Precipitation carbon absorption
Organic phosphorus	Carbon absorption

2.3 Other Problems of Pollution Related to Toxic Substances

2.3.1 Bottom sediment contamination by mercury and PCB

Toxic substances accumulated in bottom sediments affect the human health through fish and shellfish. Now in Japan, provisional removal standards for bottom sediments have been set for mercury and PCB. Contaminated sediments are removed on the basis of these standards. The standards for removing sediments are 25 mg/kg DS for mercury (this value varies according to conditions for sediments in the sea) and 10 mg/kg DS for PCB.

For mercury contaminated sediments, 42 water areas in Japan have been specified as areas where sediments must be removed according to surveys conducted since 1973. Of these, contaminated sediments have already been removed from 38 areas and sediments from the remaining water areas are now being removed.

For sediments contaminated by PCB, 79 water areas have been specified as areas for sediment removal according to surveys conducted since 1972. Of these, contaminated sediments have already been removed from 70 water areas and sediments in other two areas are now being removed.

The most typical one of these sediment removal projects is the mercury contaminated sediments removal project in the Minamata Bay, shown in Fig. 2.3.

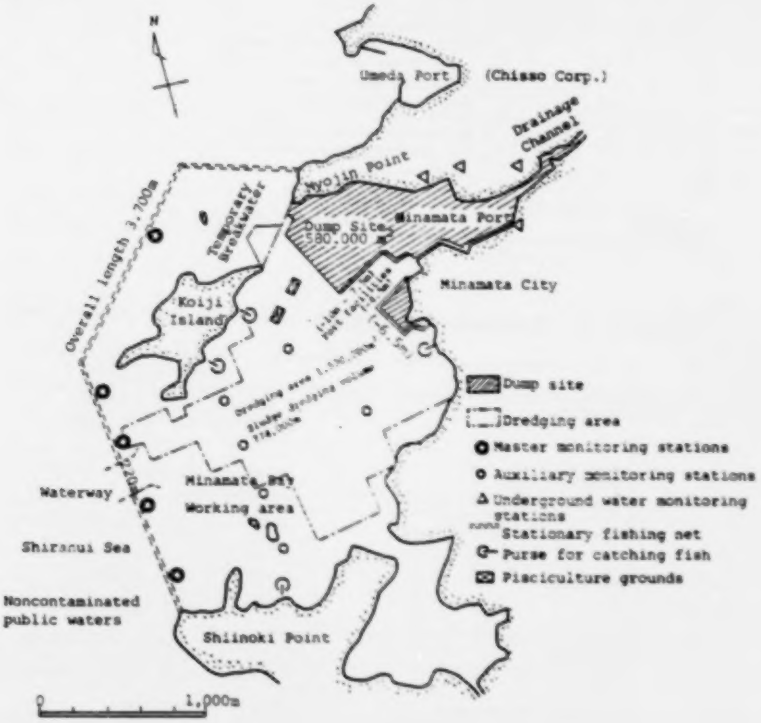

N
Umeda Port
(Chisso Corp.)
Drainage Channel
Myojin Point
Temporary Breakwater
Overall length 3,700m
Dump Site 580,000 m³
Minamata Port
Minamata City
Koiji Island
Dredging area
Sludge dredging volume
Minamata Bay
Working area
Waterway
Shiranui Sea
Noncontaminated public waters
Shiinoki Point
0
1,000m
▨ Dump site
Dredging area
● Master monitoring stations
○ Auxiliary monitoring stations
△ Underground water monitoring stations
Stationary fishing net
Purse for catching fish
Pisciculture grounds

Fig. 2.3 Dredged sediments disposal plan for Minamata Bay

The Minamata Plant of Chisso Corporation had used mercury as a catalyzer in the manufacturing process of acetaldehyde for about 40 years since 1932. The amount of mercury discharged from the plant and accumulated in the bay is estimated to have been approximately 70 to 250 tons or more. The thickness of the bottom deposit containing mercury reached 4 meters in some places in the bay. The project in this bay is to partly reclaim or dredge about 1.5 million m^3 of bottom sediments containing mercury of 25 mg/kg DS or more in concentration. In carrying out this project, to maximize safety, a strict monitoring of water quality as well as fish and shellfish has been done to prevent secondary contamination by the diffusion of bottom sediments.

In the disposal of removed bottom sediments, banks are constructed to divide the dump site and public water area, thus preventing toxic substances from flowing outside or exuding from the reclaimed area. The surface layer is covered with good quality soil, and groundwater conditions in the surrounding area are strictly monitored.

2.3.2 Groundwater contamination by chemical substances

(1) Present state of groundwater contamination

Groundwater use in Japan is about 14 billion m^3 a year. This accounts for 16 percent of the total amount water used. When restricted to water for domestic use only, groundwater accounts for 24%.

Main environmental problems for groundwater have so far been ground subsidence and salinity intrusion caused by excessive pumping of groundwater. For groundwater contamination problems, accidents caused by hexavalent chromium and cyanide have been reported in a quite few cases.

Recently, as a result of water supply surveys in some cities, there arose a suspicion of local groundwater contamination by chlorinated organic compounds. In this connection, a nationwide survey of groundwater contamination was done in 15 representative cities shown in Fig. 2.4 in 1982. The number and percentage of samples in which each pollutant was detected, and the ranges of detected concentration from this survey are shown in Table 2.7. Pollutants which were in high percentage of detection were ① nitrate and nitrite (approx. 87%), ② trichloroethylene (28%), ③ tetrachloroethylene (27%), ④ chloroform (22%), ⑤ 1. 1. 1-trichloroethane (14%), and ⑥ carbon tetrachloride (10%). According to the result of the survey in nearby rivers carried out for reference, those six pollutants were also detected highly in the river water.

No water quality standards are set for groundwater in Japan at present. However, since groundwater is used for the drinking purpose in the majority of areas throughout Japan, it is necessary to maintain the quality of the groundwater suitable for drinking water. Table 2.8 shows a comparison between the results of the above survey and the water quality standards provided by the Water Works Law in Japan, or specified in the tentative guideline for drinking water by the World Health Organization (WHO). Of the water quality parameters compared, nitrates and nitrites in 9% of the samples exceeded the water quality standard of the Water Works Law. Of the other pollutants, tetrachloroethylene and trichloroethylene exceeded the tentative guideline of WHO in 4% and 3% of samples, respectively.

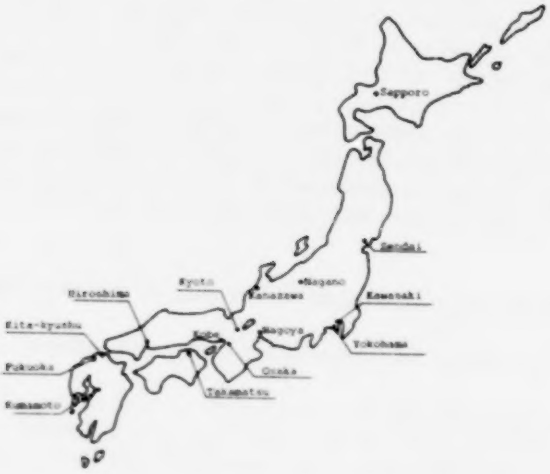


Fig. 2.4 Map of surveyed area

Table 2.7 Detection of chemical substances in ghoundwater

Classification	Shallow well		Deep well		Total		River (Reference)	
Number of samples	1,083		227		1,360		139	
Number of detected samples, etc. / Name of substance	Number and percentage of detected samples (%)	Detected range (µg/ℓ)	Number and percentage of detected samples (%)	Detected range (µg/ℓ)	Number and percentage of detected samples (%)	Detected range (µg/ℓ)	Number and percentage of detected samples (%)	Detected range (µg/ℓ)
Nitrate and Nitrite	980 (90)	20 - 80,000	202 (73)	20 - 12,000	1,182 (87)	20 - 80,000	127 (91)	20 - 25,000
Methyl chloride	2 (0)	2	0 (0)	-	2 (0)	2	0 (0)	-
Dichloro methane	5 (0)	2 - 6	1 (0)	6	6 (0)	2 - 6	9 (6)	1 - 5
Chloroform	240 (22)	0.5 - 28	65 (24)	0.5 - 31	305 (22)	0.5 - 31	40 (29)	0.5 - 13
Carbon tetrachloride	84 (8)	0.05 - 2,200	47 (17)	0.05 - 1.7	131 (10)	0.05 - 2,200	8 (6)	0.05 - 0.20
1.1-dichloroethane	20 (2)	1 - 175	9 (3)	1 - 30	29 (2)	1 - 175	0 (0)	-
1.2-dichloroethane	14 (1)	1 - 33	2 (1)	3 - 13	16 (1)	1 - 33	1 (1)	7
1.1.1-trichloroethane	142 (13)	0.2 - 1,600	44 (16)	0.2 - 70	186 (14)	0.2 - 1,600	33 (24)	0.2 - 93
1.1-dichloroethylene	10 (1)	1 - 7	3 (1)	1 - 5	13 (1)	1 - 7	0 (0)	-
Cis-1.2-dichloroethylene	88 (8)	1 - 537	31 (11)	1 - 338	119 (9)	1 - 537	2 (1)	1
Trans-1.2-dichloroethylene	15 (1)	1 - 15	5 (2)	2 - 10	20 (1)	1 - 15	0 (0)	-
Trichloroethylene	289 (27)	0.5 - 4,000	90 (33)	0.5 - 210	379 (28)	0.5 - 4,000	54 (39)	0.5 - 16
Tetrachloroethylene	289 (27)	0.2 - 23,000	88 (30)	0.2 - 190	372 (27)	0.2 - 23,000	50 (36)	0.2 - 3.0
Benzene	3 (0)	4 - 11	0 (0)	-	3 (0)	4 - 11	0 (0)	-
Toluene	12 (1)	2 - 42	8 (3)	3 - 15	20 (1)	2 - 42	2 (1)	14
Xylene	5 (0)	3 - 17	0 (0)	-	5 (0)	3 - 17	1 (1)	3
Di-n-butyl phthalate	27 (2)	2 - 48	1 (0)	8	28 (2)	2 - 48	1 (1)	9
Di-ethylhexyl phthalate	40 (4)	4 - 18	5 (2)	5 - 10	45 (3)	4 - 18	4 (3)	5 - 21

It was found by this survey that the contamination of groundwater was noticeable in a fairly wide area unexpectedly.

Therefore, a follow-up survey was made in 1983 on the same wells in 13 cities and their adjacent wells for trichloroethylene and tetrachloroethylene which were detected in high concentration in many samples in 1982.

From the results of the follow-up survey, the groundwater contamination by trichloroethylene and tetrachloroethylene was confirmed to have been noticeable in most parts of those wells and in even a wider area in many cases. Although some factories were checked to find the sources, no particular sources could not be identified.

Table 2.8 Comparision of detect concentration with water quality in Water Works Law or WHO's guideline

Classification / Name of substance	Number of samples exceeding water quality standard or WHO's guideline				Water quality standard valuer or WHO's guideline	Remarks
	Shallow well Number of surveyed wells: 1,083	deep well Number of surveyed wells: 277	Total Number of surveyed wells: 1,360	River (Reference) Number of surveyed rivers: 139		
Nitrate and Nitrite	116 (11%)	3 (1%)	119 (9%)	4 (3%)	10 mg/ℓ	Water quality standard in Water Works Law
Chloroform	0 (0)	1 (0)	1 (0)	0 (0)	30 g/ℓ	WHO's guideline
Carbon tetra-chloride	2 (0)	0 (0)	2 (0)	0 (0)	3 g/ℓ	WHO's guideline
1.2-dichloroethane	3 (0)	1 (0)	4 (0)	0 (0)	10 g/ℓ	WHO's guideline
1.1-dichloroethylene	10 (1)	3 (1)	13 (1)	0 (0)	0.3 g/ℓ	WHO's guideline
Trichloroethylene	26 (2)	14 (5)	40 (3)	0 (0)	30 g/ℓ	WHO's guideline
Tetrachloroethylene	41 (4)	12 (4)	53 (4)	0 (0)	10 g/ℓ	WHO's guideline
Benzene	1 (0)	0 (0)	1 (0)	0 (0)	10 g/ℓ	WHO's guideline

(2) Measures taken for contamination control

As a result of the nationwide surveys made in 1982-1983, the groundwater contamination was feared to be in progress in urbanized areas over a fairly wide area. Since wide area contamination of groundwater had not been revealed in the past in Japan, no primary legal control has been set for the groundwater quality.

In view of the fact that such chemicals as trichloroethylene, which contaminate groundwater, are widely used in various forms in dry cleaning industry, metal processing industry, semiconductor manufacturing industry, and many other industries, and that it is very difficult to recover groundwater once contaminated; it has been considered necessary to put some regulation toward proper use and management of these chemicals in the factories using them.

As an urgent measure, for the time being, to prevent the contamination from these chemicals, "Provisional Guideline for Discharge of Trichloroethylene and other Compounds "was set in August 1984. In this guideline, control targets are set for water quality when discharging the wastewater into goundwater or surface water. The control targets were set for trichloroethylene, tetrachloroethylene, and 1.1.1 trichloroethane; the latter's use has recently increased since it is an alternate chemical for other two. The same guideline is being applied to the discharge of wastewater to the public sewerage system. The control targets for these chemicals are shown in Table 2.9.

Table 2.9 Control targets for selected chlorinated hydrocarbons

	Control targets to prevent from penetration	Control targets for discharge into public water bodies
Trichloroethylene	Less than 0.03 mg/ℓ	Less than 0.3 mg/ℓ
Tetrachloroethylene	Less than 0.01 mg/ℓ	Less than 0.1 mg/ℓ
1.1.1-trichloroethane	Less than 0.3 mg/ℓ	Less than 3 mg/ℓ

2.4 Measures Relating to Safety of Chemicals

Chemical substances are varied in their use and types. Their number is said to reach several tens of thousands even when confined to those used in industry. Some of them are discharged into the environment during their manufacture or during various processes in their use, thus contaminating the enviroment.

To cope with this problem, the Chemical Substances Screening and Control Law was established in Japan in 1973. According to this law, new chemicals are examined, before manufacture or importation, for their three properties, namely, degradability, accumulativity and effect on human health by continuous ingestion. Any chemicals having properties of low degradability, high accumulativity and toxic effect on human health are designated as "specified chemical substances", and its manufacture, importation and use are regulated. The control system under this law is shown in Fig. 2.5.

Among new chemical substances, 2,482 were reported by industries to the government as of 31 December 1984. Of them, 1,985 chemicals were publicized by the government as not classified as the specified chemical substances and approved to be manufactured and imported.

As to existing chemical substances, investigation and checking is also under way for their biological degradability, accumulation in fish, toxicity and distribution in the environment. So far, 7 chemicals; PCB, HCB, PCN, aldrin, dieldrin, endrin, and DDT have been designated as specified chemical substances. To check the safety of existing chemical substances efficiently, a test for decomposition and accumulation is being done mainly on alternative substances those similar in structure to specified chemical substances, as well as on chemicals with large production and large imports. At the end of 1984, 511 chemicals were determined to be high in decomposition and low in accumulation.

To expedite checking of existing chemical substances earlier and more effectively, efforts are being made to develop a decomposition testing method using anaerobic bacteria, an evaluation method using physical and chemical properties of the substances, and a data reference system for information on the sefety of chemical substances.

A special investigation on the distribution and the level of chemical substances in the environment has been under way since 1974. This investigation was strengthened in 1979 and named as "comprehensive checking of chemicals in the environment" to make it more effective for systematic assessment of existing chemicals.

In this assessment system, the checking is made in three steps as shown in Fig. 2.6. In the 1st step, a screening is made for chemical substances presumed to readily remain in the environment (about 50 chemical substances/year). In the 2nd step, residual chemicals are selected (about 5 chemicals/year) by the water quality and bottom sediment surveys some ten areas throught the country, and a further detailed environmental survery on these residual chemicals is made for the water quality, bottom sediments, and in fish and shellfish in 40 areas throughout Japan. In the 3rd step, certain chemicals which reguire particular attention are screened from residual chemicals (1 or 2 chemicals in 2 years). A special test to examine their effects on the eco-system is performed with respect to these substances, and a long-term biological monitoring survey using fish, shellfish, and birds is carried out in 14 areas throughout the country.

In 1983, general environmental surveys were made on 45 chemicals. In this test, no chemical was detected from water samples, but 10 chemicals were detected from sediment samples as shown in Table 2.10. It was determined that a more detailed environmental survey would be made on 6 of those chemicals picked up by their residual results in 1984.

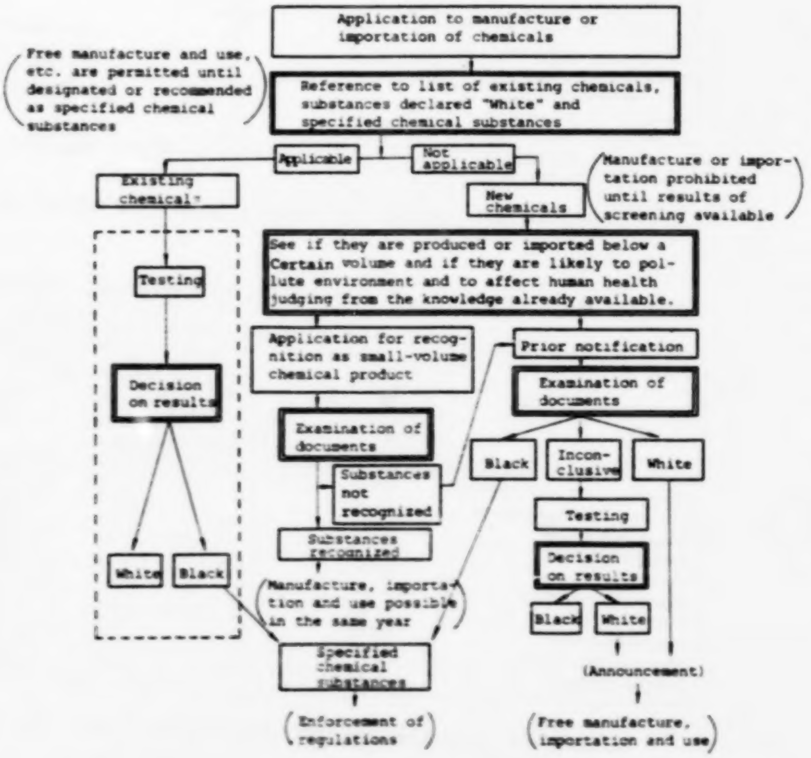

Application to manufacture or importation of chemicals
Free manufacture and use, etc. are permitted until designated or recommended as specified chemical substances
Reference to list of existing chemicals, substances declared "White" and specified chemical substances
Applicable
Not applicable
Existing chemicals
New chemicals
Manufacture or importation prohibited until results of screening available
See if they are produced or imported below a Certain volume and if they are likely to pollute environment and to affect human health judging from the knowledge already available.
Testing
Decision on results
Application for recognition as small-volume chemical product
Prior notification
Examination of documents
Examination of documents
Black
Inconclusive
White
Substances not recognized
Testing
Substances recognized
Decision on results
White
Black
Manufacture, importation and use possible in the same year
Black
White
Specified chemical substances
(Announcement)
Enforcement of regulations
Free manufacture, importation and use

Fig. 2.5 System of controls under the Chemical Substances Control Law

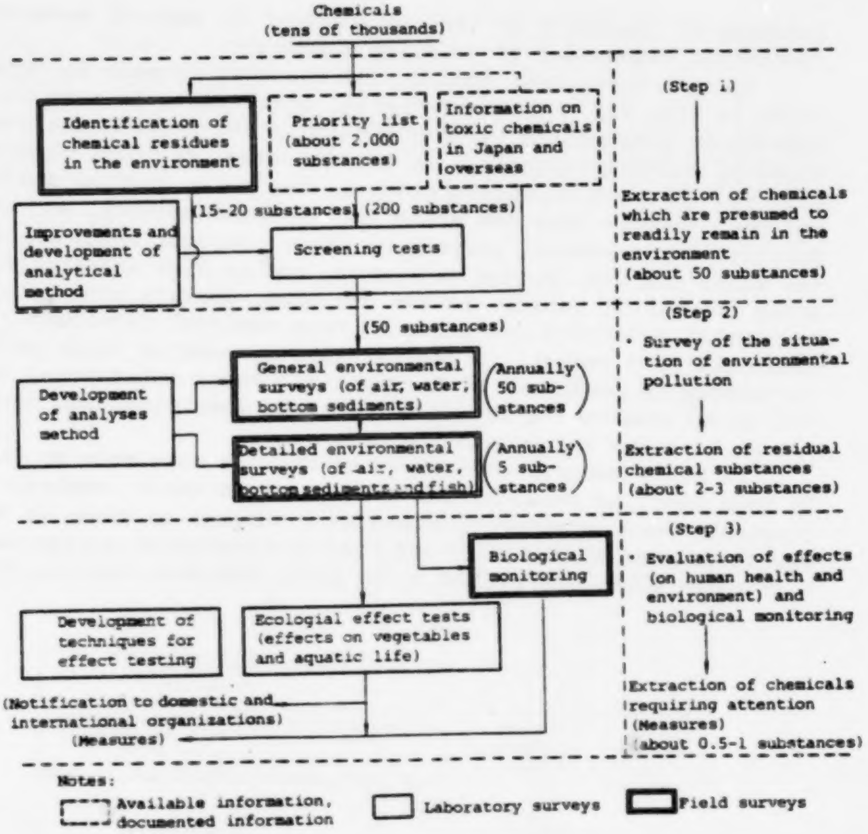

Chemicals (tens of thousands)
(Step 1)
Identification of chemical residues in the environment
Priority list (about 2,000 substances)
Information on toxic chemicals in Japan and overseas
Extraction of chemicals which are presumed to readily remain in the environment (about 50 substances)
(15-20 substances)
(200 substances)
Improvements and development of analytical method
Screening tests
(Step 2)
(50 substances)
• Survey of the situation of environmental pollution
General environmental surveys (of air, water, bottom sediments)
Annually 50 substances
Development of analyses method
Detailed environmental surveys (of air, water, bottom sediments and fish)
Annually 5 substances
Extraction of residual chemical substances (about 2-3 substances)
(Step 3)
Biological monitoring
• Evaluation of effects (on human health and environment) and biological monitoring
Development of techniques for effect testing
Ecologial effect tests (effects on vegetables and aquatic life)
(Notification to domestic and international organizations)
(Measures)
Extraction of chemicals requiring attention (Measures) (about 0.5-1 substances)
Notes:
Available information, documented information
Laboratory surveys
Field surveys

Fig. 2.6 Scheme of total checks of chemicals

Table 2.10 Result of general environmental survey (1983)

Name of substances	Water		Bottom sediments	
	Incidence of detection/ Number of samples	Detected range (μg/mℓ)	Incidence of detection/ Number of samples	Detected range (μg/g·dry)
Tributyl tin compounds	0/75	nd	9/75	0.05 - 0.70
Dibutyl tin compounds	0/75	nd	3/75	0.02 - 0.03
Acenaphthylenc	0/33	nd	13/33	0.008 - 0.053
Acenaphthene	0/33	nd	13/33	0.008 - 0.13
Fluorene	0/33	nd	27/33	0.003 - 0.091
Diphenyl methane	0/33	nd	3/33	0.059 - 0.16
2-Naphthylamine	0/48	nd	5/48	0.0017 - 0.0079
Benzothiazole	0/30	nd	4/30	0.0016 - 0.0033
Dibenzothiophene	0/45	nd	6/45	0.001 - 0.005
P-Bromophenol	0/33	nd	5/33	0.02 - 0.03

Remark: "nd" indicates that the concentration is less than detectable limits.

3. CURRENT STATUS OF SLUDGE TREATMENT AND DISPOSAL IN JAPAN

3.1 Introduction

As of the end of March 1985, municipalities operating public sewer systems totaled 496, and the number of cities started to implement sewage treatment operations has increased significantly within past several years. Table 3.1 shows the increase in the number of municipalities that have started operation of sewage treatment.

Table 3.1 The number of municipalities that have started sewage treatment operations (cumulative total)

Fiscal year / Size of municipality	'71	'75	'76	'77	'78	'79	'80	'81	'82	'83	'84
Population in thousands persons More than 1000	6	10	10	10	10	10	10	10	10	10	10
300 to 1000	15	37	37	37	37	38	38	44	44	44	45
100 to 300	63	87	95	97	101	104	107	116	120	120	123
Less than 100	64	93	109	127	143	174	198	212	236	281	318
Total	148	227	251	271	291	326	353	382	410	455	496

The total amount of sewage sludge produced in these treatment plants from April 1983 to March 1984 was about 2,200,000 m^3/year. As shown in Table 3.2, 67% of the sludge was disposed of by landfill, 9% by coastal reclamation 10% by ocean disposal, and 14% was utilized as resources such as agricultural use.

Table 3.2 Status of sewage sludge disposal

(From April 1, 1987 to March 31, 1984)

(In 1,000 m^3)

Method of disposal / State of sludge	Landfill	Coastal reclamation	Utilization as resources	Others	Total	(%)
Dewatered cake	1,241	127	246	44	1,658	(75)
Ash	229	75	30	0	334	(15)
Dried sludge	10	0	30	0	40	(2)
Digested, thickened sludge	2	0	4	168	174	(8)
Total	1,482	202	310	212	2,206	
(%)	(67)	(9)	(14)	(10)	(100)	

Thus, the greater part of sewage sludge is disposed by landfill. As cities continue to expand, finding sites for landfill has become increasingly difficult. In large cities and their peripherals it has become especially difficult for an individual municipality to independently secure a potential disposal site. To cope with these problems, there has been an increasing need for sewerage authorities to take an regional approach to prepare for proper disposal site or to seek the possibility of using more sludge as resources.

To achieve a stable and ever-lasting disposal of sludge, efforts should be made to facilitate its reuse by recognizing sewage sludge as a useful resource. The status of sludge reuse were as shown in Table 3.3 according to the survey made in 1984. The total amount of reuse achieved was about 310,000 m^3, almost all of it was for agricultural use. The greater part of agricultural use was done in a state of dewatered cake.

Table 3.3 Status of utilization of sludge as resources

(From April 1, 1983 to March 31, 1984)

State of sludge Classification		Dewatered cake	Ash	Dired sludge	Compost	Digested sludge	Total
Agricultural use	Executed by local municipalities	193	3	5	18	4	223
	Delivered to fertilizer companies	53	6	0	7	0	66
	Subtotal	246	9	5	25	4	289
Construction materials		0	21	0	0	0	21
Total		246	30	5	25	4	310

As of the end of March 1985, public organizations that are utilizing sludge as resources are 6 prefectures and 92 local municipalities, including Tokyo. The number of sewage treatment plants is 118. The greater part of farmland in Japan consists of paddy fields for growing rice, where the use of sewage sludge is difficult and therefore, sludge is used for farmland and green spaces other than paddy fields.

Even though the greater part of the reuse of sludge is in the form of dewatered cake, a certain amount of sludge is used after being composted for farmland application. The advantages of composting are easiness in handling and minimum odor. These properties are quite desirable because of the agricultural situation in Japan, wherein the lifestyle of farmers has become urbanized, the farmers are getting old, and the houses have come to be nearer the farmland. Besides these points, when the reuse of sludge in farmland or in green spaces is attempted, care should be taken in regard to the quality of sludge products to keep the soil free from pollution by heavy metals. Efforts should be made to help people understand the usefulness of sludge products by distributing information on its proper use.

The use of sewage sludge as a construction material could be a promising way because of sludge's good potentiality for this kind of use. Research and investigations on this matter have been continued by the government, by municipalities, and by private companies. The Ministry of Construction has been continuing research on the use of sewage sludge as construction materials in the comprehensive technical development project.

As a result, it has been shown that sewage sludge has bright prospects of being used as molten sludge, light weight aggregate, and ceramic materials. Because feasibility studies have proved that these objects can be achieved technically and economically, the on-site use and the establishment of a distribution system will be the next subjects.

3.2 Improvement in the Incinerating Process for Energy Conservation

3.2.1 General

As the sewer systems are expanded, the quantity of sewage sludge produced is continuously increasing. There has been a necessity, therefore, to reduce the quantity of sludge to be disposed of and to stabilize its quality because of the difficulty in securing sites for disposal and the environmental problems. This has resulted in an increase in the quantity of sludge incinerated. Table 3.4 shows the change in the total capacity of sewage incinerators during post several years.

Table 3.4 Change in Total Capacities of Sewage Sludge Incinerators in Japan

Tons of Wet Cake/day

1978	1979	1980	1981	1982
7,917	8,469	9,091	10,042	10,557

Inasmuch as a great deal of auxiliary fuel was required to incinerate the dewatered cake, with energy crises on two occasions in 1973 and 1975 being the turning points, technologies for achieving energy-saving, resource-saving, and incinerating systems with less air pollution have considerably progressed.

Generally speaking, to maintain a stable autogeneous combustion in an incinerator, a conventional multiple-hearth furnace requires a cake with a lower heating value of about 600 Kcal/kg-cake, and a conventional fluidized bed reactor requires about 800 Kcal/kg-cake. From a view point of heat balance, measures to save energy in incineration can be classified into the following three categories:

(a) increase in the heating value of the cake, (b) decrease in the amount of exhaust gas and lowering its temperature, and (c) effective use of the exhaust heat.

3.2.2 Example of improvement in an existing multiple-hearth furnace

Takaoka City improved their seven-hearth incinerators at the Yotsuya Sewage Treatment Plant, and has been operating them without any auxiliary fuel for the past several years. The major improvements being made were as follows: (Fig. 3.1):

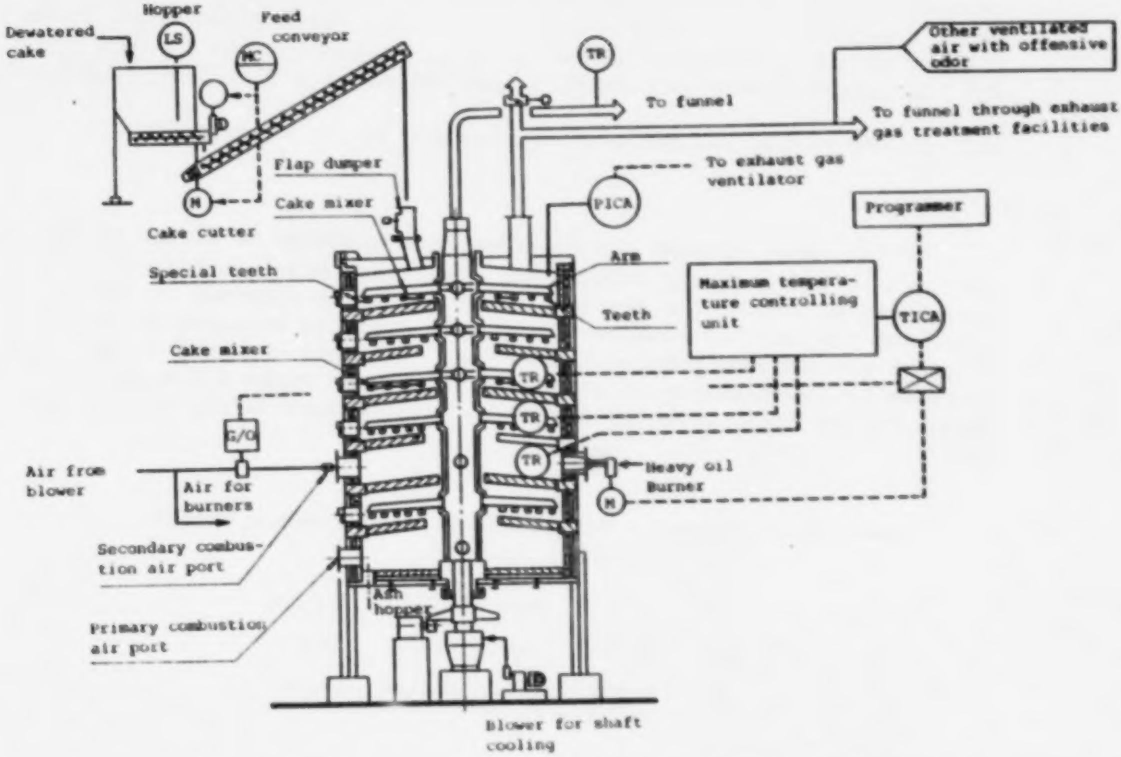

Hopper
LS
Dewatered cake
Feed conveyor
MC
TR
To funnel
Other ventilated air with offensive odor
To funnel through exhaust gas treatment facilities
Flap dumper
To exhaust gas ventilator
Cake mixer
PICA
Programmer
M
Cake cutter
Special teeth
Arm
Teeth
Maximum temperature controlling unit
TICA
Cake mixer
TR
TR
TR
G/O
Air from blower
Air for burners
Heavy oil Burner
M
Secondary combustion air port
Primary combustion air port
Ash hopper
ID
Blower for shaft cooling

Fig. 3.1 Schematic diagram of the multiple-hearth incinerator of the Yotsuya STP, Takaoka City Improved for energy saving

(a) The primary combustion air was taken by means of natural ventilation from the bottom (7th) furnace, and the secondary air was supplied at normal temperature at the 5th hearth.

(b) Cake mixers were installed at the 1st and the 3rd hearths in addition to the normal teeth to assure complete mixing.

(c) Special teeth were used at the 4th and the 5th hearths to reduce short circuit.

(d) A controlling system was introduced, which could maintain the optimum temperature in the incinerator at a constant level by manipulating the secondary combustion air supply. This control was effective to reduce the air supply.

(e) Heating value of the cake was improved by changing the dewatering method. High pressure belt presses were used with a polymer and ferric chloride addition. Water content of the cake is normally about 70%.

The limit of the lower heating value for autogeneous combustion with this improved multiple-hearth furnace is 350 to 370 Kcal/kg-cake. The range of loading with which autogeneous combustion is possible is from 32% to 135% of the design loading when the low heat value of the cake is more than 400 Kcal/kg-cake.

Heat losses due to unburned sludge and radiation account for only 3% of the total heat input to the incinerator.

The combustion air supply system of this furnace, that is, to supply the primary air by natural ventilation from the bottom hearth and to control the secondary air supply so as to maintain the temperature at the combustion hearths at 800 to 900°C, was found very effective against variation of sludge cake loading and fluctuation of heating value of the cake.

3.2.3 Example of improvement in a fluidized bed furnace

The Arakawa Basin-wide Sewage Treatment Plant of Saitama Prefecture employed a fluidized bed furnace with a preliminary sludge drier using exhaust heat to decrease the auxiliary fuel requirement.

The schematic diagram of the furnace is shown in Fig. 3.2.

In this system, the heat of the exhaust gas is recovered at the heat exchanger, and the recovered heat is supplied to a sludge drier in the form of heated oil at temperature about 250°C. The drier is an hollow screw type of indirect heating. The evaporated vapour is returned to wastewater treatment process after condensation, and the exhaust gas with some offensive odor is supplied to the freeboard of the furnace for deodorization.

The percentage of moisture evaporated at the drier is about 25% of the original water content. The lower heating value becomes twice as much as that of the sludge cake before drying. The reduction of the auxiliary fuel consumption is 60 to 100% as shown in Fig. 3.3

3.3 Development in Technology to Produce Compost from Sewage Sludge

3.3.1 General

To facilitate the use of sewage sludge for farmland and green spaces, it is desirable to improve the characteristics of the dewatered cake for its safety, stability, and easiness in handling. To counter these problems, technology has rapidly developed to produce sewage sludge compost capable of maintaining a stable quality through an aerobic fermenting process.

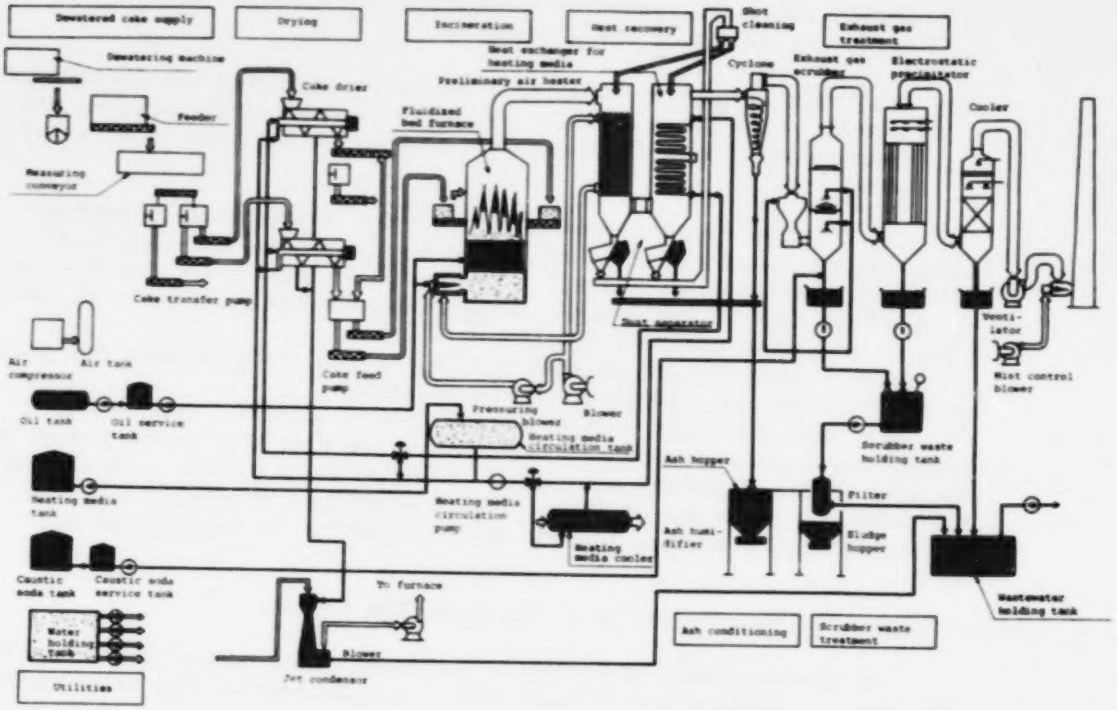

Dewatered cake supply
Drying
Incineration
Heat recovery
Dust cleaning
Exhaust gas treatment
Dewatering machine
Heat exchanger for heating media
Preliminary air heater
Cyclone
Exhaust gas scrubber
Electrostatic precipitator
Cake drier
Feeder
Fluidized bed furnace
Cooler
Measuring conveyor
Cake transfer pump
Dust separator
Venti-lator
Air compressor
Air tank
Cake feed pump
Mist control blower
Oil tank
Oil service tank
Pressuring blower
Blower
Heating media circulation tank
Scrubber waste holding tank
Ash hopper
Heating media tank
Heating media circulation pump
Filter
Ash humi-difier
Sludge hopper
Heating media cooler
Caustic soda tank
Caustic soda service tank
To furnace
Wastewater holding tank
Water holding tank
Blower
Ash conditioning
Scrubber waste treatment
Jet condensor
Utilities

Fig. 3.2 Schematic diagram of the fluidized Bed Furnace of the Arakawa Basin-wid SCP Improved for Energy Saving

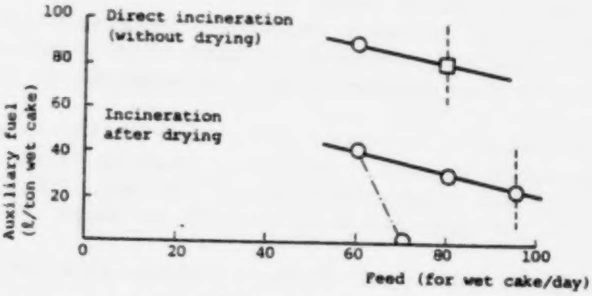


Fig. 3.3 The effect of sludge drying on auxiliary fuel reduction

The following characteristics are expected for the composted sludge.

(1) Reduction in the easily biodegradable organic content and increase in stability.

(2) Improvement in easiness of handling by reduction of water content.

(3) Extermination of pathogenic bacteria and parasites' eggs.

(4) To meet the standards relating to heavy metals as a special fertilizer regulated by the Fertilizer Management Law, which is shown in Table 3.5.

As to application of sewage sludge to farmland, a management guideline was stipulated using Zinc as an index as shown in Table 3.6.

Table 3.5 Standards concerning heavy metal contents in special fertilizers (Regulations by the Fertilizer Management Law)

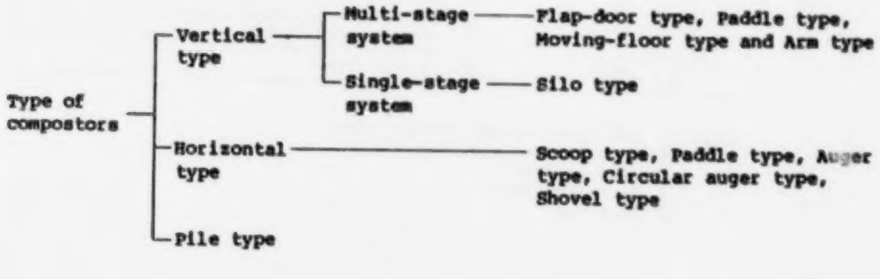
Item	Standard
Arsenic	Less than 50 mg/kg DS
Cadmium	Less than 5 mg/kg DS
Mercury	Less than 2 mg/kg DS

Table 3.6 Management guideline to prevent the accumulation of heavy metals in the soil of farmland
(Notification of Water Quality Protection Bureau of the Environment Agency)

1. The index for controlling accumulation of heavy metals in the soil of farmland shall be the zinc content.
2. The management guideline relating to controlling accumulation of heavy metals in the soil of farmland shall be 120 mg of zinc per 1 kg of dry soil.
3. The analytical method to measure the zinc content in the surface soil shall be the atomic absorption spectrophotometry following the digestion by mineral acids.

3.3.2 Methods of composting

The methods for producing compost using sewage sludge can be classified depending on the types of fermentation tank. Each type of method could be further classified depending on with or without addition of bulking agent and with or without preliminary drying of the dewatered cake prior to composting.


Type of compostors
Vertical type
Multi-stage system
Flap-door type, Paddle type, Moving-floor type and Arm type
Single-stage system
Silo type
Horizontal type
Scoop type, Paddle type, Auger type, Circular auger type, Shovel type
Pile type

3.3.3 Design data for composting facilities

The first sewage sludge composting facility in Japan started operation in 1976 and composting does not have a long history. Therefore, concrete design criteria have not been established yet. Table 3.7 summarizes the range of design data of the composting facilities based on experiments and actual facilities.

Table 3.7 Composting facility design data

	Item	Data values	Remarks
Pre-conditioning	Water content of feed mixture (%)	① 40 - 55 ② 60 - 70	The feed mixture means input materials to the ferment tank that is a mixture of raw materials (cake and bulking agent) and the return compost.
	Feed mixture pH (-)	About 8 to 10	When pH of the dewatered cake is excessively high, an adjustment is necessary.
	Bulking agent N (% - WB)	② 15 - 40	$N = \frac{\text{Bulking agent's wet weight (kg/day)}}{\text{Dewatered cake's wet weight (kg/day)}}$
	Return ratio Rc (% - WB)	① 100 - 300 ② 30 - 100	$Rc = \frac{\text{Return compost's wet weight (kg/day)}}{\text{Dewatered cake's wet weight (kg/day)}}$
Primary Fermentation and Secondary Fermentation	Apparent specific gravity (t/m^3)	(Feed mixture) ① 0.65 - 0.75 ② 0.50 - 0.65	(Primary compost, secondary compost) 0.60 - 0.80 0.65 - 0.75
	Fermentation period	Primary fermentation Secondary fermentation	10 to 14 days (Forced ventilation) 7 to 14 days) (Natural ventilation) 1 to 2 months
	Pile height (m)	Primary fermentation ③ Silo type 3.0 - 5.0 ③ Other than silo type 0.6 - 1.4 ④ Shovel type 2.5 - 3.0 ④ Other than shovel type 1.0 - 1.5 ⑤ (Natural ventilation) 1.0 - 2.0 ⑤ (Forced ventilation) about 2.5 The pile height for secondary fermentation is about 1 - 1.3 times as high as that for primary fermentation.	
	Frequency of mixing (days)	Primary fermentation / Secondary fermentation ③ 0.5 - 4 / 7 - 14 ④ Shovel type 4 - 7 / 7 - 14 ④ Other than shovel type 1 - 3 / 7 - 14 ⑤ (Natural ventilation) 0.3 - 0.5 / 7 - 14 ⑤ (Forced ventilation) - / 2 - 10	
	Air supply	100 - 200 $\ell/min \cdot m^3$	

Note: ① Composting without bulking agent
② Composting with bulking agent
③ Vertical type
④ Horizontal type
⑤ Pile type

3.3.4 Composting facilities under operation

As shown in Table 3.8, composing of sewage sludge is being done at 15 cities as of the end of October 1984. The capacities of the facilities are from 3 tons of wet cake a day to 206 tons of wet cake a day. For promoting the agricultural use of sewage sludge compost, an efficient and stable distribution system needs to be structured with a consideration for competition with conventional fertilizers both chemical and organic and through the cooperation with farmers associations and private businesses, depending on the actual situation of the districts.

3.4 Development of a Technology Producing Construction Materials from Sewage Sludge

3.4.1 Possibility of sludge utilization

Composting is a technology to utilize organic subtances contained in sludge, whereas production of construction materials from sludge is a technology to utilize mineral contents of sludge such as SiO_2, $A\ell_2O_3$, Fe_2O_3, and CaO.

(1) Dewatered cake

Direct use of dewatered cake for banking or filling materials is not practical because of problems such as insufficient strength, subsidence due to compaction and leachate. However, after mixing with incinerated ash or cement, it has been used for that purpose to some extent.

(2) Incinerated ash

When the ash is compacted under conditions near an optimum water content, the finished product has the sufficient ground-resistant force required for the construction machine operation, and exhibits a consistency near that of sandy soil. Therefore, it is suitable for use in a wide range of construction materials, such as road foundation, banking, and landfill.

The possibility of its indirect use has been explored extensively for various purposes including production of light weight aggregates, clay pipes, bricks, earthenwares concrete products such as Hume pipe, or additives for cement. Some of them, such as production of light weight aggregates, which is explained more in detail below, are very promising. For producing clay pipes, it was found that ash can be added up to about 25% without problems.

Table 3.8 Sewage sludge composting facilities under operation

Installation site		Composting facilities					
Name of city	Name of plant (Date of completion)	Addition of bulking agents	Primary fermentation			Secondary fermentation	
			Type	Capacity and number of units	Fermenting period	Method	Fermenting period
				ton/day x number	days		days
Tendo city	Tendo sewage treatment plant (April 1979)	With addition	Vertical silo type	5 x 1	14	Indoor piling	40 - 60
Yamagata city	Maeakashi cake treatment plant (April 1980)	Without addition	Horizontal shovel type	15 x 1 (8-tanks)	12	Included in primary fermentation	-
Akita city	Akita city compost center (April 1982)	With addition	Vertical multi-stage paddle type	30 x 1	12	Indoor piling	15
Hitachi city	Namekawa sewage treatment plant (Oct. 1982)	Ditto	Vertical multi-stage flap-door type	15 x 1 (2-tanks)	35	Included in primary fermentation	-
Tokyo	Minamitama sewage treatment plant (May 1980)	Without addition	Horizontal scoop type	7 x 1 (4-tanks)	10	-	-
Kasugai city	Kozoji sewage treatment center (April 1984)	Ditto	Horizontal scoop type	13 x 1	14	-	-
Okayama city	Takashima sewage treatment center (April 1981)	With addition	Vertical two-stage paddle type	0.72 x 1	14	Open-air piling	About 60
Koriyama city	Koriyama city sewage treatment center (April 1983)	Without addition	Horizontal scoop type	12.2 x 1 (3-tanks)	14	Included in primary fermentation	14
Ibaragi Pref.	Kasumigaura sewage treatment center (April 1984)	Ditto	Horizontal scoop type	3 x 1	16	Ditto	14
Tokorozawa city	Tokorozawa sewage treatment center (Sept. 1983)	Ditto	Vertical multi-stage paddle type	10 x 1	10	-	-
Kayano city	Lake Shirakaba sewage treatment center (Sept. 1983)	Ditto	Horizontal scoop type	3 x 1 (2-tanks)	10	-	-
Nozawa hotspring village	Nozawa hotspring village sewage treatment center (April 1983)	Ditto	Vertical multi-stage type	4 x 1 (2-tanks)	10	-	-
Sapporo city	Atsubetsu sludge compost plant (April 1984)	Ditto	Horizontal paddle type	50 x 1 (4-tanks)	12 - 13	Indoor piling (Forced ventilation)	
Kagoshima city	Kagoshima city sewage sludge compost plant (april 1981)	Ditto	Vertical silo type	53.6 x 1 (8-tanks)	8	Horizontal shovel type	30
Kofu city	Otsu sewage treatment plant (April 1984)	With addition	Vertical silo type	17.5 x 1	14	Indoor piling (Forced ventilation)	60
Mobara city	Kawanakajima sewage treatment plant (Aug. 1984)	Ditto	Vertical multi-stage flap-door type	8.8 x 1	21	Horizontal shovel type (Forced ventilation)	30
Fukuoka city	Fukuoka sewage sludge control center (Jan. 1982)	Without addition	Horizontal shovel type	206 x 1 (13-tanks)	30	(Entrusted with private businesses)	

(3) Smelted slug

The smelted slug satisfies almost all of the conditions required for the materials sustitute for sands or gravels. In addition, it has an advantage of no resolubilization of heavy metals. The only problem is the cost, and efforts are being made to reduce the production cost, as well as to find the other uses which justify the higher cost.

3.4.2 Production of light weight aggregate from incinerated ash

This technology was developed by paying attention to the similarity of the constituents of incinerated ash to shale, which is the light weight aggregate raw material. The Metropolitan Tokyo Government constructed a multi-stage jet-flow furnace with a capacity of 3 tons a day, which is shown in Fig. 3.4, and has been producing light weight aggregates as a routine practice.

Aggregates are produced in such a way that a bonding agent (waste alcohol liquor) is added to ash to give it viscosity, and the mixture is subsequently granulated and dried. It is then burned in an air current heated to a temperature of from 1,100°C to 1,150°C and cooled. During burning, a portion of the constituent is gasified, causing the granules to inflate. While cooling, the granules maintain their inflated volume, and the finished products have cavities inside and a hard shell outside. The specific gravity of the product is 1.3 to 1.65, which is only half that of gravel or sand. It is easy to produce completely spherical aggregates with a diameter of from 0.3 mm to 3.5 mm. The strength of the aggregates is considerably high. The destruction strength is about several kilograms per granule. It lends itself to many uses. Direct uses are for backfill materials for shield tunnelling, aggregates for permeable pavement, block wall material, and precast outer wall material. Indirect uses include backfill material for sewer construction, tennis court floor materials, and supporting materials for potted growth of plants.

The Metropolitan Tokyo Government has entrusted with certain experienced private companies the distribution of the lightweight aggregates on an experimental basis to investigate the types of suitable and potential markets, the estimated future demand, the required quality, and the appropriate prices. The percentages of the product classified by use in fiscal 1983 are shown in Table 3.9.

Although selling prices differ depending on the types of packing, the amount of sale, and the types of shipping work, the product is being marketed at a price of from about 9,500 yen/ton to 20,000 yen/ton. Problems still to be solved include restructuring of shipping facilities and warehouses, arranging bagging facilities, integrating production and shipments, and optimizing the amounts of production and sales.

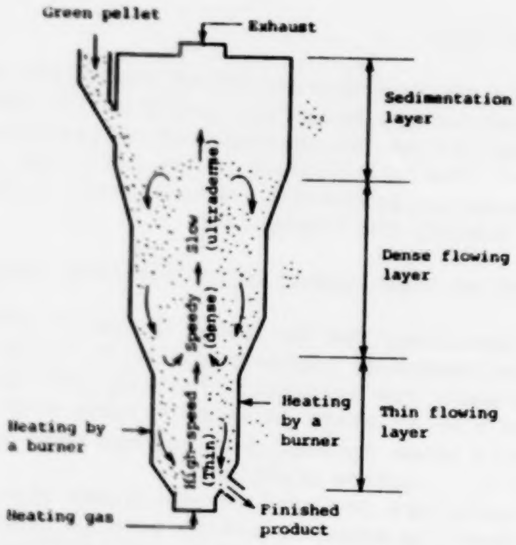

Green pellet
Exhaust
Sedimmentation layer
Slow (ultradense)
Dense flowing layer
Speedy (dense)
Heating by a burner
Thin flowing layer
Heating by a burner
High-speed (Thin)
Heating gas
Finished product

Fig. 3.4 Schematic diagram of a multi-stage jet flow furnace

Table 3.9 Use of light-weight aggregate made from sewage sludge

(FY 1985, Metropolitan Tokyo)

Use	Reason of use	Amount of use	
		Quantity	Percentage
Filling materials for underground storage of liquid combustibles	Absolute dryness	163 t	67%
Aggregate for GRC products	Light-weight	47 t	10%
Aggregate for resin concrete and other resin	Absolute dryness, Light-weight	25 t	10%
Cement concrete, and other construction materials	Light-weight, Absolute dryness, Fire-resistant, Sound proof	3 t	1.5%
Gardening, filter media, and others	High void ratio, water absorption characteristics, light-weight	4 t	2.5%
Total	-	242 t	100%

3.5 Regional Plan for Treatment and Disposal of Sewage Sludge

3.5.1 Current status of sludge treatment and disposal in the Tokyo Bay and Osaka Bay basins

Both Tokyo Bay and Osaka Bay are symbolic water bodies from the viewpoint of maintaining proper water quality of Japan's coastal sea. The statistics in 1983 show that the Tokyo Bay basin (Metropolitan Tokyo, Chiba Prefecture, and Kanagawa Prefecture) has a total areas of 8,591 km^2, a population of 25.1 million and total of 169 local municipalities including cities, towns, and villages. The Osaka Bay basin has a total area of 7,441 km^2, a population of 16.1 million, and total of 123 local municipalities. Both are densily populated developed areas (Table 3.10)

Table 3.10 Outline of the Tokyo Bay and Osaka Bay basins

(1983)

Basin	Tokyo Bay	Osaka Bay
Area (km^2)	8,591	7.441
Prefecture	Metropolitan Tokyo, Chiba, Saitama and Kanagawa Prefectures	Osaka, Kyoto, Hyogo, and Nara Prefectures
Number of municipalities	169 (23 wards, 97 cities, 44 towns, and 15 villages)	123 (66 cities, 53 towns, and 4 villages)
Population (person)	25,093,236	16,137,972

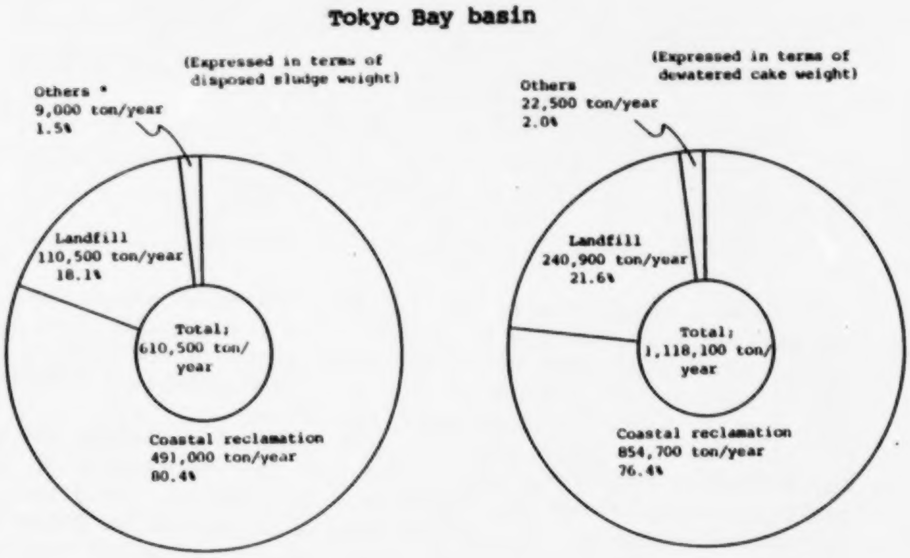
Japan's total area is 377,765 km^2, and total population is 119 million, of which the Tokyo Bay basin accounts for 2.5% in area and 21% in population. The Osaka Bay basin accounts for 2.0% in area and 14% in population. Both districts also have prominent industrial areas, with a great number of sources of pollution.

In order to comply with the environmental standards set for Tokyo Bay and Osaka Bay it was considered that the enforcement of the effluent quality regulation was not sufficient in strength. This has resulted in an implementation of the loading regulation system for Tokyo Bay in 1979 and for Osaka Bay in 1980. The water quality parameter regulated by this system is COD_{Mn} at present, but a guide line was also issued to control the total loading of phosphorus. To comply with the regulation and to improve the water quality of the bays, the construction of sewerage systems is one of the most effective measures. The current status of sewerage systems in Tokyo Bay and Osaka Bay Basins in 1983 is shown in Table 3.11.

Table 3.11 Current status of sewerage systems in the Tokyo Bay and Osaka Bay basins

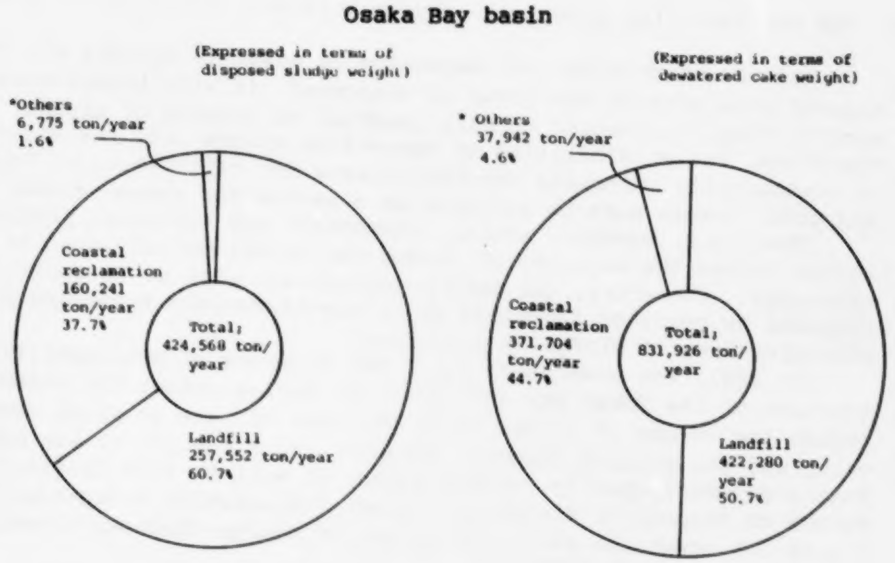
Basin	Tokyo Bay	Osaka Bay
Population	25,093,236	16,137,972
Population served	11,726,506	7,760,513
Percentage	46.7	48.1

The total volume of sewage sludge produced during one year in 1980 was 1,120,000 m^3 in Tokyo Bay and 830,000 m^3 in Osaka Bay, respectively, expressed in terms of dewatered cake. As shown in Fig. 3.5, the greater part of dewatered cake produced was disposed of by landfill; a very small amount was applied to form land and green spaces.



* "Others" means sludge utilized for farmland and green spaces.

Fig. 3.5 The amount of sludge classified by disposal methods in 1980



* "Others" means sludge handed to fertilizer

Fig. 3.5 The amount of sludge classified by disposal methods in 1980 (Cont'd)

Because of the difficulty in obtaining proper site for sludge disposal due to an increased density of population in these areas, local municipalities are anxious to secure potential sites for the disposal of sludge. Most of the minicipalities have disposal sites of capacities only less than five years. Some local municipalities have been seeking sites to dispose of sludge, where are more than 100 km apart from their home teritories, because no proper site in their districts are available (Table 3.12).

Table 3.12 Distance from the sewage treatment plant to the landfill site (1980)

Classification / District	Transportation distance and the number of sewage treatment plants				
	Less than 10 km	10 - 20 km	20 - 50 km	50 - 100 km	More than 100 km
Tokyo metropolitan district	8	13	5	2	9
Kinki district	17	14	4	0	6
Total	25	27	9	2	15

Note: In the Tokyo metropolitan district, sewage treatment plants operating in Tokyo, Chiba, Saitama, and Kanagawa prefectures are taken for investigation. In the Kinki district, those in Osaka, Kyoto, Hyogo, and Nara prefectures are taken for investigation.

3.5.2 The necessity for a regional sludge treatment and disposal plan

Because of progress and expansion in sewerage systems and the necessity to advance the level of treatment, it will become more and more difficult to depend on only landfill to dispose of sludge. Therefore, the possibilities of converting sludge into resources, such as construction materials and fertilizers for cultivation of farmland and green spaces must be explored as a method for sewage sludge disposal.

There are, however, social, economical and technical problems to be solved before the majority of sludge can be effectively used as resources. Therefore, the most practical way will be to continue the disposal by means of landfills while simultaneously expanding the effective uses of sludge as resources.

In 1981, the government asked the opinions of municipalities within the area of the Tokyo Bay and Osaka Bay basins, about the measures to reduce the volume of sludge to be disposed of, the problems associated with, and the planned disposal methods. As a result, it was made clear that every municipality considers that it will be more difficult in the future to dispose of sludge in its own jurisdiction independently. Figure 3.6 shows the estimated amount of sludge disposed classified by disposal methods in 1995.

Tokyo Bay basin

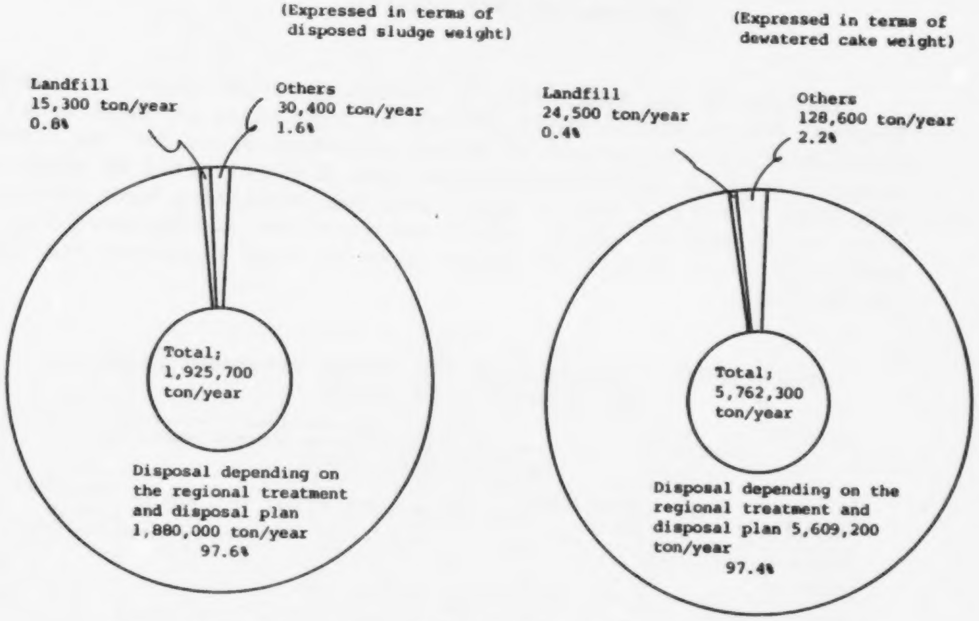


Fig. 3.6 The estimated amount of sludge classified by sludge disposal methods in 1995

Osaka Bay basin

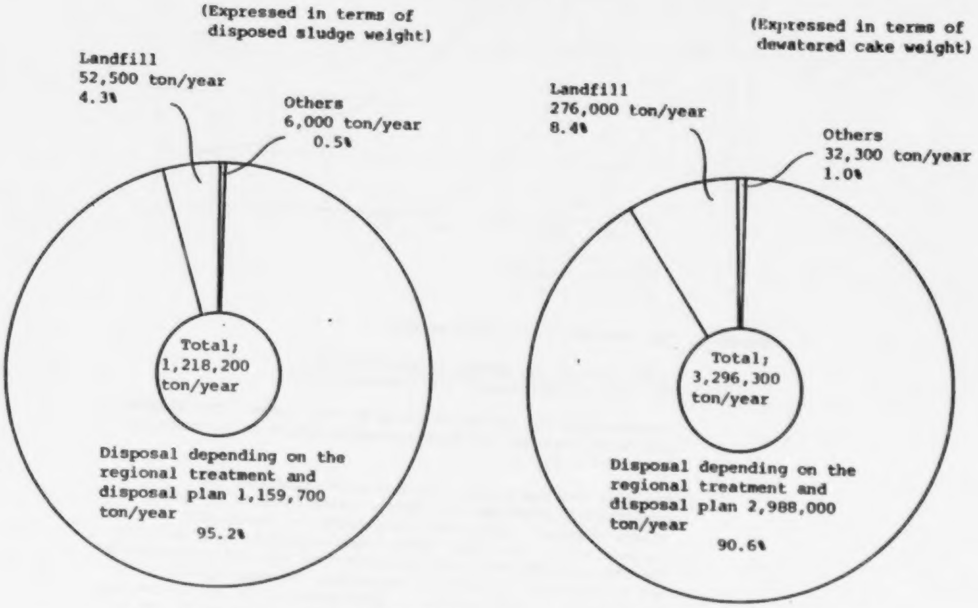
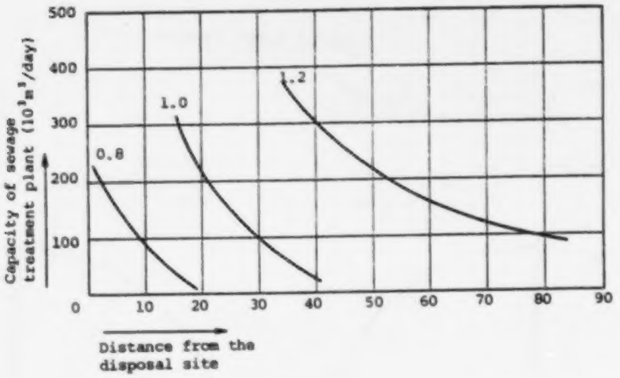


Fig. 3.6 The estimated amount of sludge classified by sludge disposal methods in 1995 (Cont'd)

The ratio of the sludge disposed of by means of landfill is expected to be just 0.8% in the Tokyo Bay basin and 4.3% in the Osaka Bay basin, respectively. The ratio of the sludge utilized for farmlands or other resources is estimated to be only 1.6% in the Tokyo Bay basin and 0.5% in the Osaka Bay basin, respectively. The amount of sludge that are expected to be disposed of by means of the regional plan accounts for 98% in the Tokyo Bay basin and 95% in the Osaka Bay basin, respectively.

To carry out regional treatment and disposal of sludge, it is necessary to collect sludges by some means. As the result of a study on the sludge collection system from both technical and economical viewpoints, it was found that collecting raw sludge to a central sludge treatment plant by a pipeline followed by dewatering and incineration is more advantageous than the dewatering and incineration at each treatment plant when the transportation distance is within 20 to 30 km (Fig. 3.7).



Notes: 1. The numerals in the diagram are

$$\frac{\text{The case of raw sludge transportation}}{\text{The case of incinerated ash transportation}}$$

representing the ratios of costs to each other. The diagram indicates that the raw sludge transportation is possible at less than 1.0.

2. The cost for raw sludge transportation includes the construction expenses of transportation facilities, joint sludge disposal facilities (thickening → dewatering → incineration), and their maintenance expenses. The cost for the incineration ash transportation includes the construction and maintenance expenses of the sludge disposal facility (thickening → dewatering → incineration) in the individual treatment plant and also the expense for transporting the incinerated ash to the disposal site.

Fig. 3.7 Review on the characteristics of sludge collected and the total cost of sludge disposal

In consideration of the current status of sludge disposal in both Tokyo Bay and Osaka Bay basins and of the opinions of local municipalities, a regional sludge treatment and disposal plan including the effective use of sludge, needs to be materialized.

3.5.3 A conception of a regional sewage sludge treatment and disposal plan

On the basic assumption that landfill will be continued for the time being but that there will be a gradual shift to other effective ways such as utilization as resources, the following business concept is under review.

(1) A centralized sludge treatment plant including incineration is constructed on the landfill site, and sludge within an area of 20 to 30 km range from this centralized plant is collected by means of a pipeline. In the future, the disposal of the greater part of the sludge will be shifted from landfill to such effective uses as construction materials.

(2) As to treatment plants outside 20 to 30 km range from the centralized plant, such effective uses as the agricultural use of composted sludge should be considered as a first choice.

(3) When the agricultural use is not possible, and when reduction of the sludge volume is needed, a joint incineration will be taken.

(4) As for the site for landfill of incinerated ash or dewatered cake the coastal reclamation site for regional is to be jointly used, and simultaneously landfill sites in the inland area are to be seeked for.

3.5.4 A detailed plan in the Osaka Bay basin

Of the two districts of Tokyo Bay and Osaka Bay basins, the necessity for the regional treatment and disposal plan is much higher for the Osaka Bay basin being highly desirable and advantageous from an economical viewpoint.

(1) Disposal districts

The project area needs to be divided into disposal districts for actual planning, paying attention that the collection, transportation, and treatment of sludge will be performed in an efficient and economical manner from a long term view point, even when an effective use of sludge becomes possible in the future.

In the Osaka Bay basin, three disposal districts were formulated as shown in Fig. 3.8 considering the following conditions:

(a) The time when each sewage treatment plant wants to join the regional sludge treatment and disposal plan

(b) The economy of sludge collection, including the basic assumption of pipeline collection within 20 km range from the central sludge treatment plant.

(c) Long rivers, such as Yodo River, as a boundary.

(2) Planning the pipeline transportation of liquid sludge

The liquid sludge (with a water content of 90%) within 20 km range is to be pumped from the sludge storage tank at each sewage treatment plant to the central sludge treatment plant through a pipeline. All pipeline system will be constructed as a dual-line structure for easiness in repair and in coping with increase in the amount of sludge as time goes. A relay pumping station will be installed where the length of the pipe becomes about 10 km or more.

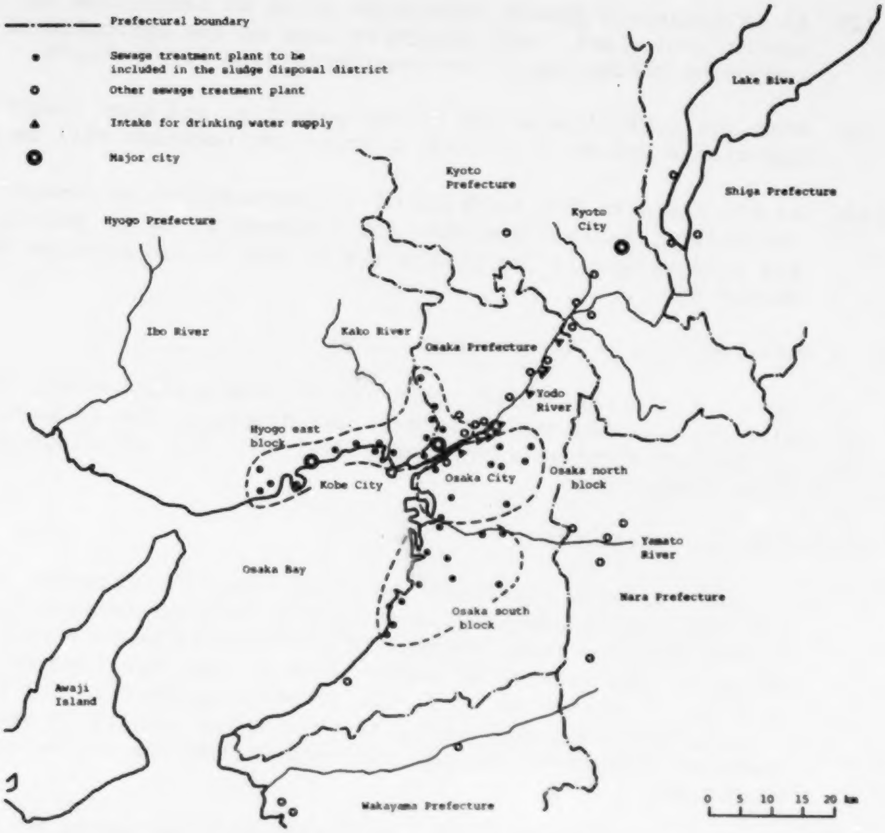

Prefectural boundary
Sewage treatment plant to be included in the sludge disposal district
Other sewage treatment plant
Intake for drinking water supply
Major city
Lake Biwa
Kyoto Prefecture
Shiga Prefecture
Kyoto City
Hyogo Prefecture
Ibo River
Kako River
Osaka Prefecture
Yodo River
Hyogo east block
Kobe City
Osaka City
Osaka north block
Yamato River
Osaka Bay
Nara Prefecture
Osaka south block
Awaji Island
Wakayama Prefecture
0 5 10 15 20 km

Fig. 3.8 Map of the Regional Sludge Treatment and Disposal Plan

(3) The central sludge treatment plant

The basic policy on sludge treatment and disposal is to reduce the volume of sludge as much as possible for conserving the disposal site for the time being, and to shift gradually from landfill to utilization and of sludge other effective purposes. To meet these requirements, thickning → dewatering → incineration (melting) system will be employed. Returning wastewater treatment facility, a control building and an electrical room will also be installed at the site.

The block diagram of sludge collection, treatment and disposal system is shown in Fig. 3.9, and an example of the layout of a central sludge treatment plant is shown in Fig. 3.10.

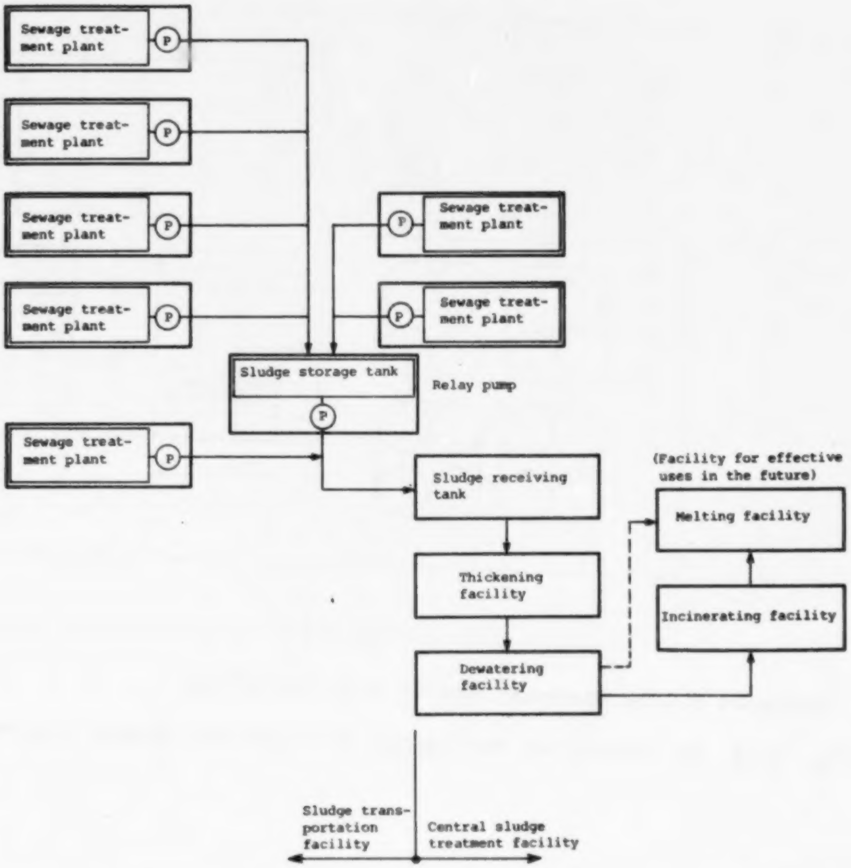
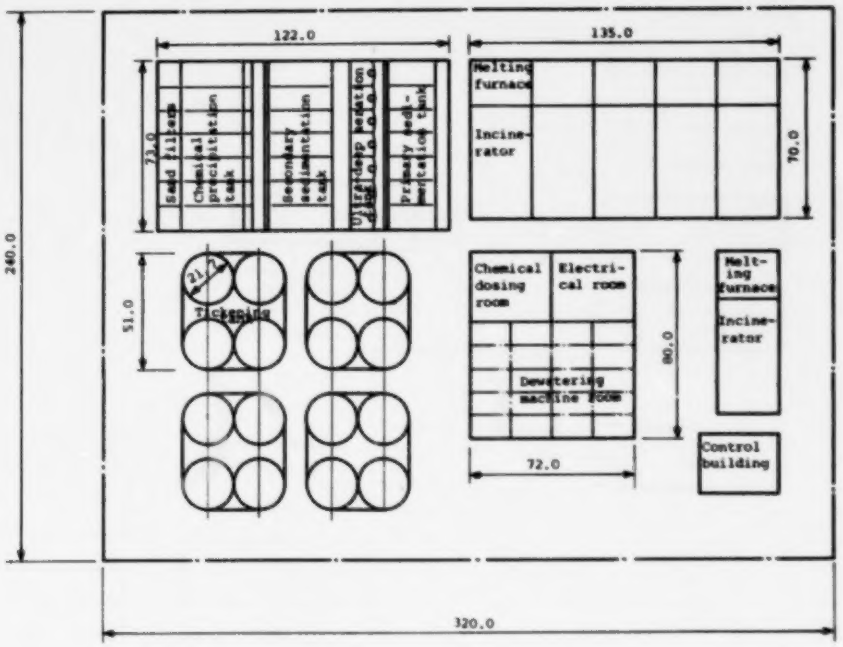

Sewage treat-
ment plant
P
Sludge storage tank
Relay pump
Sludge receiving tank
(Facility for effective uses in the future)
Melting facility
Thickening facility
Incinerating facility
Dewatering facility
Sludge trans-
portation
facility
Central sludge
treatment facility

Fig. 3.9 Block diagram of sludge collection, treatment and disposal system

(4) Economical analysis

The regional sludge treatment and disposal plan was formulated as a long-term plan extending about 24 years, from 1986 to 2010. The construction of this facility was planned on the assumption that national grant would be provided, as in the case of the public sewerage system. The results of trial computation on the revenue and expenditure of the projects relating to each disposal district shows that in order to make the cumulative account positive 10 and 20 years after the project starts, the treatment and disposal cost per unit volume of liquid sludge should be 575 - 730 yen/m^3 and 570 - 695 yen/m^3, respectively. These costs are cheaper than those when sludge is treated and disposed at each existing treatment plant, which is 680 - 2,770 yen/m^3.

The construction case of the facilities at each disposal district is estimated to be from 63.3 billion yen to 81.4 billion yen.


122.0
135.0
73.0
Sand filter
Chemical precipitation tank
Secondary sedimentation tank
Ultradeep aeration tank
Primary sedimentation tank
Melting furnace
Incinerator
70.0
240.0
51.0
21.7
Thickening tank
Chemical dosing room
Electrical room
Dewatering machine room
80.0
72.0
Melting furnace
Incinerator
Control building
320.0

Designed sludge disposal amount = 35,500 m^3/day

Fig. 3.10 An example of the layout of a central sludge treatment plant

4. RECENT TECHNOLOGICAL DEVELOPMENT IN WASTEWATER TREATMENT

4.1 Overview

In the recent technical advances of wastewater treatment in Japan, large cities, the Ministry of Construction, and the Japan Sewage Works Agency have had leading roles. Technical development has especially been made in such large cities as Tokyo, Osaka, and Yokohama, where the sewage works have been carried out since the 1920s. Progress in technology has been particularly notable in such fields as the development of equipments, the vertical utilization of wastewater treatment plant sites, the improvement of dewatering machines and incinerators to reduce the volume of sludge, and the development of automation and instrumentation. All these technologies were essential to the construction of wastewater treatement plants in Japanese large cities where the population density is extremely high.

The Ministry of Construction is responsible for the administration of the sewage works in Japan. It has been planning and funding the research and development programs relating to common and urgent problems in conducting sewage works. Most of the actual research works are carried out by three institutions, namely, the Water Quality Control Division of the Public Works Research Institute of the Ministry of Construction, the Research and Technical Development Division of the Japan Sewage Works Agency, and the Japan Sewage Works Association.

The research projects, including those performed by the Ministry of Construction itself, in fiscal 1984 were as follows. The greater part of them are being continued for FY 1985.

(1) Researches on rational design methods for wastewater treatment facilities

- Comprehensive planning for offensive odor control
- Evaluation of the effect of the nutrient load reduction on lake eutrophication control
- Treatment methods for storm sewage
- Investigations on the fate of micropollutants within the wastewater treatment processes

(2) Researches on treatment and disposal of sludge

- Guidelines on the use of sludge for green spaces and agricultural land
- Testing methods for converting sludge into construction materials
- Investigations on ocean disposal and land reclamation of sludge.
- Investigations on improving the management techniques of sludge dewatering processes

(3) Researches on advanced wastewater treatment processes and the reuse of the effluent

- Research on the reuse of treated effluent
- Research on removal of nutrients in wastewater

- Research on removal of dissolved organics in wastewater
- Soil treatment of secondary effluent for nutrient removal

(4) Research on development of automatic water quality monitoring devices for controlling industrial discharge

(5) Research on resource and energy conservation in sewerage facilities

- Guidelines for coincineration of sewage sludge and municipal refuse
- Research on the recovery of energy through sludge digestion

(6) Research on the small wastewater treatment system

- Research on the treatment characteristics of small wastewater treatment plants
- Research on development of facilities suitable for a small wastewater treatment plant

Private industries have also played preeminent roles in developing new technologies in Japan. Many of their research and development have attained highly advanced technical levels. Therefore, it is necessary to promote technical cooperation with these private industries for carrying out sewage works effectively and properly.

There has been, however, a tendency for a sewerage authority to take a cautious attitude toward employing new technology developed by a particular private company for sewerage construction projects, which are inherently public-oriented projects.

This has been attributable to the followings:

(1) The source of funds for construction are completely the public expenses, such as those originating from taxes.
(2) The economical benefit induced by the use of new technology may not be evaluated readily, and
(3) Any failure resulting from the use of a new technology cannot be tolerated easily.

Therefore, to utilize the fruitful results of new technologies developed by private industries, there was a necessity to formulate a proper system for evaluating these new technologies.

The Ministry of Construction has established a new technology assessment system in 1978. This system is intended to evaluate properly the functions and performances of new technologies developed by private industries and to promote actual use of these new technologies extensively by disclosing publicly the results of the evaluation. The Minister of Construction announces the particular technology to be assessed in an official publication and invites private industries to submit applications for assessment. An assessment certificate is issued to each applicant after the assessment is completed.

Table 4.1 summarizes the subjects on which the assessment has been made.

Table 4.1 Themes of technology assessment by Ministry of Construction

Fiscal year of invitation	Subjects	Objects of development	Goals of development	Issuance date of the evaluation certificate
1978	Development of microwave furnace for sewage sludge to melt	To develop microwave melting furnace capable using microwaves to melt and solidify sewage sludge, turning it into chemically stable glassy material without however generating harmful exhaust gas but permitting, the melted and solidified substances to be used as construction materials.	1) Maximum treating capacity of furnace of about 5 tons/day. 2) Exhaust gas generated from the process, being capable of meeting the requirements set forth in Air Pollution Prevention Law (Law No. 97 in 1968). 3) Melted and solidified glassy materials being capable of meeting the Order of Prime Minister's Office (Order No. 5 in 1973) determining the criteria for industrial wastes. 4) Melted and solidified glassy substances being capable of providing the strength required for aggregates. 5) Comparatively low costs of manufacturing, operating and maintaining the melting furnace.	September 1979
1979	Development of large-diameter egg-shaped hard vinyl chloride pipe with high rigidity	To develop hard vinyl chloride pipe having an egg-shaped section with excellent hydraulic properties, large diameter, sufficient strength and endurance.	1) Strength determined by the flat test (in accordance with test method established by Standard K-1 of Japan Sewage Works Association) being capable of meeting the strength of class 1 centrifugal reinforced concrete pipe (external pressure strength against cracking load of JIS A 5303). 2) Nominal diameter of about 500 mm. 3) Endurance almost equal to or higher than that of class 1 centrifugal reinforced concrete pipe.	July 1980
1980	Development of ultra-deep aeration system for sewage treatment	To develop activated sludge process using ultra-deep aeration tank requiring only a small area.	1) Required processing capacity greater than 1,000 m^3/day. 2) Process providing values of biochemical oxygen demand (BOD) and suspended solids (SS) of final effluent capable of meeting the technical requirements set forth in Para. 1 of Article 6 of the Enforcement Ordinance of Sewarage Law (Cabinet Order No. 147 in 1959). 3) Simple operation. 4) Low maintenance and management costs. 5) Simple environmental measures.	July 1981

Table 4.1 Themes of technology assessment by Ministry of Construction (Cont'd)

Fiscal year of invitation	Subjects	Objects of development	Goals of development	Issuance date of the evaluation certificate
1981	Development of energy-saving type aerator by diffused air.	To develop energy-saving type aerator to be used for diffused air type activated sludge process at the sewage treatment plant.	1) Power consumption is to be reduced by more than 20% compared to conventional air diffusing equipment. 2) For ordinary sewage, the aerator is to be able to provide the values of biochemical exygen demand (BOD) and suspended solids (SS) of final effluent meeting the technical requirements set forth in Para. 1 of Article 6 of the Enforcement Ordinance of Sewerage Law. 3) Connection to existing aeration tank is to be easily made. 4) Simple operation.	July 1982
1982	Development of mechanical aerator for oxidation ditch process	To develop efficient mechanical aerator using oxidation ditch process as one of sewage treatment methods.	1) Required current speed is to be obtained. 2) Oxygen is to be efficiently supplied. 3) Sufficient mixing and agitating ability. 4) Easy equipment maintenance and operation. 5) Simple environmental measures.	July 1983
1983	Development of sewage solid-liquid separation method by screen process	To develop solid-liquid separation process using screens for economically separation of sewage solids from liquids, conventionally performed with settling basin.	1) Quality of treated water almost equal to that of settling basin is to be obtained. 2) Eeasiness in operation and maintenance. 3) Sufficient durability. 4) Economical operation and maintenance.	July 1984
1984	Development of highly efficient belt-press for sewage sludge dewatering	To develop a belt-press capable of efficiently dewatering sludge to obtain a cake with low moisture content.	1) The system must have a highly efficient dewatering capability. 2) Easiness in operation and maintenance. 3) Sufficient durability. 4) Economical operation and maintenance.	Expected to be July 1985

As seen in the Table 4.1, four subjects are related to wastewater treatment, two are related to sludge handling, and one is related to sewers.

The period required for assessment under this system is about one year from the time of inviting applications until completion of assessment, thus making a quick evaluation possible. This is a very convenient system for assessing equipments or machinery within short period of time, but is not suitable system for evaluating treatment processes which requires usually a relatively long time to evaluate.

The Japan Sewage Works Agency has a technology evaluation committee which was established in 1974, to evaluate new technologies, particularly treatment processes. This committee consists of representatives from the

Ministry of Construction and Local municipalities as well as from the academic circle.

The President of the Japan Sewage Works Agency asks the committee to evaluate a particular technology, and the committee discusses the features and the functions of the technology, the scope of its applicability and the design parameters based on the data obtained from actual plants employing the technology. The committee prepares a evaluation report which is incorporated into the design criteria of the Japan Sewage Works Agency to be reflected in the Agency's daily operations. The official report is published openly, and those published so far have contributed greately not only to the Japan Sewage Works Agency but also to the Ministry of Construction, local municipalities and private industries for proper utilization of the new technologies.

Table 4.2 shows the technologies that have been evaluated by the committee so far.

Table 4.2 Technologies evaluated by the JSWA evaluation committee

Items submitted for deliberation	Date of inquiry	1st report	2nd report	3rd report
① Automatic control of sewage treatment plant	July 1974	Oct. 1975	June 1980	Aug. 1983
② Oxygen-activated sludge process	July 1974	Oct. 1975	Nov. 1978	June 1981
③ Existing sludge incinerating facilities	July 1975	June 1980	-	-
④ Single hearth cyclonic furnace	Aug. 1977	Oct. 1980	-	-
⑤ Evaporation-dewatering-incinerating process (C-G process)	Aug. 1977	Aug. 1979	-	-
⑥ RBC for small flow wastewater treatment plant	Aug. 1977	Nov. 1978	Dec. 1982	-
⑦ Sewage sludge composting facilities for agricultural use of sludge	June 1981	-	-	-
⑧ Oxidation-ditch process	Dec. 1982	Dec. 1983	-	-

Technologies evaluated by the Japan Sewage Works Agency's system are in principle those being developed competitively by several companies, and those being already used at some actual treatment plants. The field data for evaluation are collected by the personnel of the Agency over a necessary period of time, and are submitted to the evaluation committee after analysis.

Design and O & M manuals for the new technology are usually prepared after the report of the evaluation committee is published.

The Public Works Research Institute of the Ministry of Construction is reviewing the existing rules so that joint research with private companies can be positively under-taken. The joint research projects on development and utilization of biotechnology in wastewater treatment will be the first case of joint research with private companies. The Japan Sewage Works Agency has a provision on the joint research with private companies since 1984. The projects being carried out now include the sequencing batch activated sludge process, a simplified sludge collector for a small flow sewage treatment facility, and a technique to reduce phosphorus returned from the sludge treatment process dealing with excess sludge from biological phosphorus removal process.

To carry out this joint research project, the expenses generally are shared evenly between the Agency and the private company, and the fruits of the project such as patents are also shared equally.

In the following, some typical instances of the recent technological development in Japan are outlined.

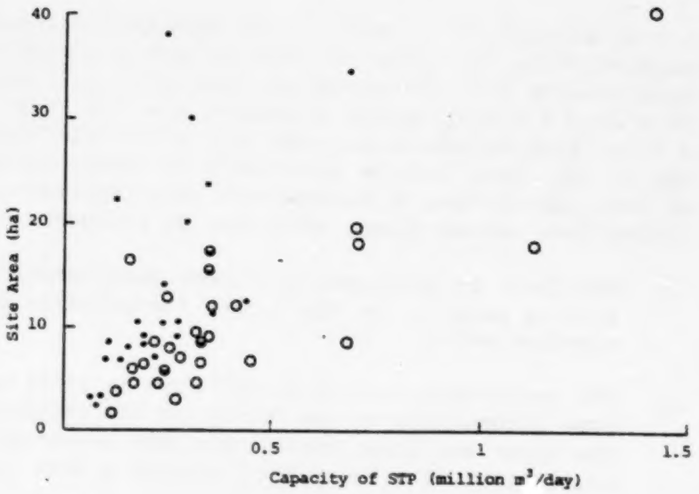
4.2 Some Typical Examples of the Recent Technological Development

4.2.1 Multiple deck sedimentation tank and deep aeration tank

In Japan, the area of a wastewater treatment plant site is generally determined to be roughly 4.5 times as large as the area required for the major treatment facilities and service passages. In such large cities as Tokyo, Osaka, and Kyoto, however, it is often difficult to obtain a land enough as prescribed in the guidelines mentioned above, for reasons of cost and availability of land. Also, room must sometimes be left for the future expansion or for constructing advanced wastewater treatment facilities.

In addition, special considerations often become necessary in heavily urbanized area to take coordination between wastewater treatment plant and its surrounding environment or residents by means of multipurpose use of the site. Under these circumstances, the concept of the high degree and vertical uses of a treatment plant site was introduced around 1960, and the design method for a multiple deck sedimentation tank and a deep aeration tank have been established. In most cases, these facilities are designed to have covers, and the top of the cover are utilized as a park, tennis courts or similar facilities.

In Fig. 4.1, the comparison of site areas for wastewater treatment plants with multiple deck sedimentation tanks and/or deep aeration tanks and for those with conventional design is shown. The average site area of a wastewater treatment plant per unit capacity of the plant is about 0.5 m^2/m^3/day in Japan. The site area in Metropolitan Tokyo, however, is just 0.3 m^2/m^3/day on the average.



- ○ STP with multiple deck settler and/or deep aeration tank
- ● STP with conventional design
- ⊙ STP that part of its facility is multiple deck structure

Fig. 4.1 Comparison of site areas for sewage treatment plants with multiple deck settlers and/or deep aeration tanks and for those with conventional design

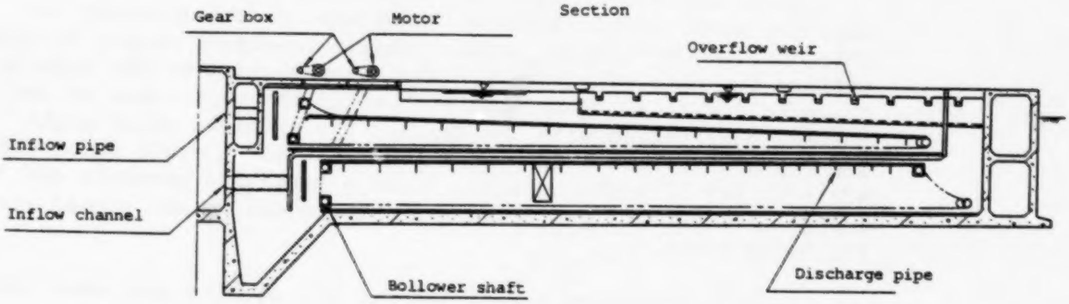

Gear box
Motor
Section
Overflow weir
Inflow pipe
Inflow channel
Bollower shaft
Discharge pipe

Fig. 4.2 Double deck secondary sedimentation tank

(1) Sedimentation tank

The concept of surface loading proposed by T.R. Camp indicates that the removal by sedimentation can be determined only by the surface loading to the sedimentation tank. Experience suggests that the suitable ranges of surface loadings for primary and secondary sedimentation tanks are 20 to 50 m^3/m^2/day and 20 to 30 m^3/m^2/day, respectively. However, when the sedimentation tank is structured into two stories or more by placing one on the top of another, it is possible to acquire the treatment capacity multiplied by the number of stories with the same site area. The first double deck sedimentation tank (Fig. 4.2) was constructed in 1964 at the Ochiai Sewage Treatment Plant in Tokyo. Later in Osaka, a three deck sedimentation tank was constructed for more effective use of the site. As the experience of construction and maintenance of these facilities is accumulated, the important points in the design have become clear, which are as follows:

ⓐ The flows in the upper and lower decks should be made equal as much as possible by the proper installation of valves and overflow weirs.

ⓑ The sedimentation tank should also be structured so that no scum accumulates on the bottom of the partitioning slab between the upper and lower decks; this can be accomplished through the utilization of a lower deck rake as a scum collector.

ⓒ Smooth collection and withdrawal of sludge should be guaranteed by proper equipments and maintenance, which include the use of a durable link belt, careful consideration about the shape and capacity of the sludge hopper, and a device to prevent the sludge withdrawal pipe from clogging.

(2) Deep aeration tank

In 1970, the Metropolitan Tokyo Government decided to employ aeration tanks with a depth of 10 meters for constructing the Shingashi and Morigasaki Higashi sewage treatment plants in order to utilize the site effectively. The cross section of the tank is shown in Fig. 4.3. This plan was beyond the experience of the conventional design with 5 m depth. The problems which might associate with such a deep aeration tank were thought to be the adaptability of microorganisms to high hydraulic pressure and the energy efficiency. The tests made before design had proved the following facts:

(a) The microorganism activities did not decline even when the cyclic hydraulic pressure of 0 to 20 m was repeatedly applied.

(b) As shown in Fig. 4.4 the theoretical energy required to supply unit volume of air increased as the depth of the diffuser increased. When this relationship was expressed by an exponential function of the depth H as αH^{β}, the exponent β was roughly 0.7. On the other hand, the oxgen transfer capacity was also found to increase proportionally to the 0.7th power to the depth H as shown in Fig. 4.5. Therefore, it was found that the energy efficiency was not dependent on the depth of the tank.

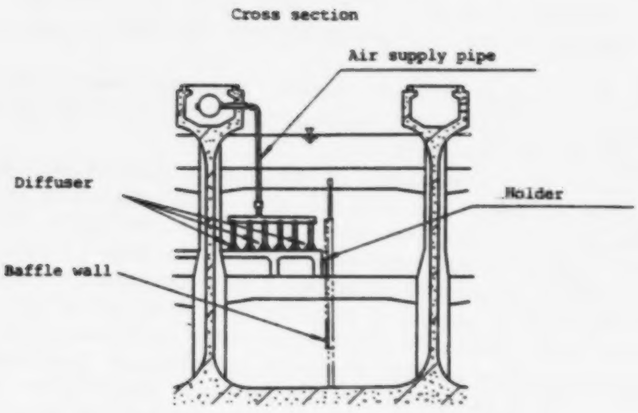
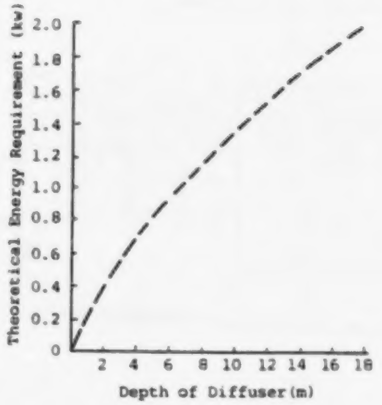


Fig. 4.3 Deep aeration tank



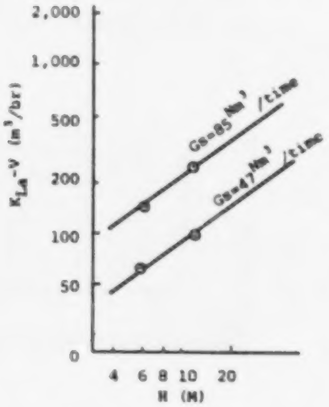


Fig. 4.4 Relationship between Theoretical Energy Requirement and the Depth of Diffuser

Fig. 4.5 Relationship between Overall Oxygen Transfer Rate $K_{La} \cdot V$ and the Depth of Diffuser H

(c) When the depth of the diffuser was more than 5 meters, it became difficult to continue stable treatment because of poor settlability of sludge due to gassification of the supper-saturated air.

From these experiences, it was concluded that the following consideration should be taken for the design of the facility:

(a) To prevent activated sludge from floating, the diffuser is placed at about a depth of 5 meters, not near the bottom of the tank.

(b) To assure good mixing even with an increased cross sectional area, it is necessary to use the baffle walls effectively.

The design concept noted above has been employed in the "Design Criteria for Sewerage Facilities" issued by the Japan Sewage Works Association.

In fact, 7 wastewater treatment plants out of 10 plants in service in Tokyo, or 55% of the total capacity of 5,880,000 m^3/day, are those employing multiple deck sedimentation tanks and/or deep aeration tanks. In Osaka City, among 12 wastewater treatment plants, 8 plants employ multiple deck primary sedimentation tanks, 4 plants have deep aeration tanks, and 10 plants have multiple deck secondary sedimentation tanks. Another fomous example is the kisshoin wastewater treatment plant in Kyoto. This treatment plant employs the oxygen activated sludge process, and the aeration tank is installed above the final sedimentation tank. (Fig. 4.6.) Coupled with the effective use of space created on the top of the cover of the treatment facilities, the greater part of the facilities to be constructed in big cities in the future will employ this kind of technique.

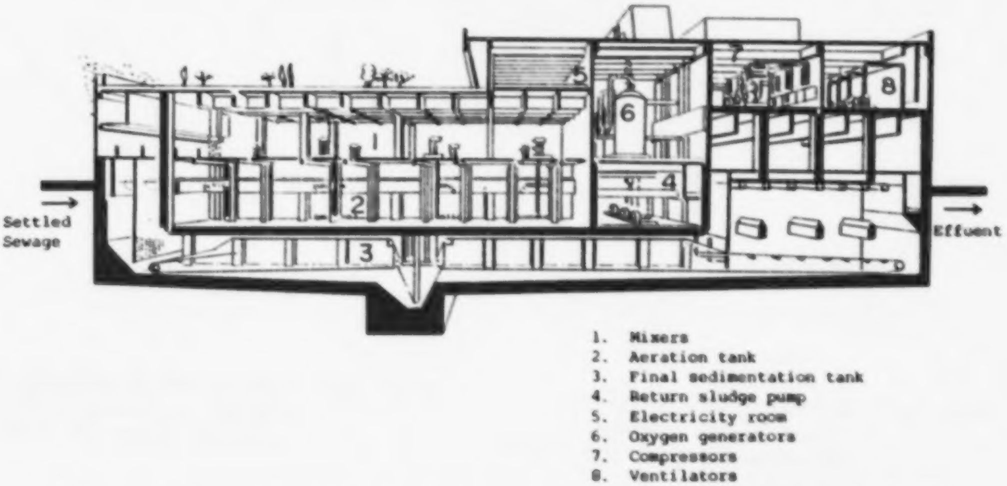


Fig. 4.6 Perspective view of secondary treatment facilities of the Kisshoin STP in Kyoto

4.2.2 Phosphorous and nitrogen removal technology

In 1972, the Public Works Research Institute of the Ministry of Construction established a pilot plant with a treatment capacity of 250 m^3/day at the Shimomachi Sewage Treatment Plant in Yokosuka City, and started the research on removal of phosphorous from secondary effluent by means of chemical coagulation. This was the start of the research on advanced wastewater treatment technology in Japan. Since then, research and development for advanced treatment technology has come to be carried out extensively by major research institutions including Research Division of the Japan Sewage Works Agency Tokyo and other large cities.

Research at the beginning focused on physical-chemical treatment. However, after the energy crisis in autumn in 1973, the saving or conserving of resources and energy has become a demand of society, and therefore, the emphasis on research and development for advanced treatment technology shifted to the biological removal of phosphorous and nitrogen.

During these periods, phosphorous removal by addition of a coagulant to the aeration tank has been put to practical use. This method has been employed by the wastewater treatment plants at Lake Kasumigaura and Lake Biwa. In addition to minimize the amount of sludge being generated, the crystalization method has been developed. This method is to crystallize orthophosphate ions on the surface of the contact media as calcium hydroxyapatite. In 1983, a full-scale plant with a capacity of 12,000 m^3/day was built by Metropolitan Tokyo.

As for the biological nitrogen removal process the single stage nitrification and denitrification process with nitrified liquor recycle has been put to practice as a means of removing nitrogen. The Konan Chubu Sewage Treatment Center in the Lake Biwa area began to operate in April 1982 as a full scale facility employing this method.

At a small sewage treatment plant in Hamamatsu City, biological denitrification by the Wuhrmann process, which utilizes endogeneous respiration, has been successfully carried out using the facility which originally designed as an extended aeration process. An anaerobic section is installed in the latter half of the aeration tank.

The first full-scale evaluation project of the biological phosphorus removal process in Japan was performed by the Japan Sewage Works Agency at the Arakawa Sewage Treatment Center in 1982. Since then, researches for practical application have started at many treatment plants in various cities such as Hamamatsu, Kawasaki, Kyoto, Tokyo, Fukuoka and so forth.

One of the major targets of research on biological phosphorus removal in Japan is to find the method to stabilize the treatment even during the rainy season and the typhoon season in the summer time; another target might be to pursue measures to reduce the return load of phosphorous from the sludge treatment processes.

Another research field of interest is to reduce the capacity of a nitrification tank by increasing the efficiency of nitrification. The effect of installing rotating disks or other media in the aeration tank has been studied at various institutions by pilot scale experiments. Application of biotechnology for improving the efficiency of nitrification has also been persued at many research institutions. Also, as an advanced wastewater treatment process for a small flow treatment plant, nitrogen and phosphorous removal by sequencing batch activated sludge process has been studied.

Table 4.3 shows a list of wastewater treatment plants that have been performing phosphorous and nitrogen removal as a routine practice. Besides these plants, many demonstration projects for biological phosphorus and nitrogen removal have been carried out at many places, including Tokyo, Kyoto, and Osaka cities.

Table 4.3 List of wastewater treatment plants employing advanced wastewater treatment technology for phosphorous and nitrogen removal

Receiving water body	Name of wastewater treatment plant	Design capacity (m^3/day)	Treatment method
Lake Kasumigaura	Kasumigaura Wastewater Treatment Center	55,400	Nitrified Liquor recycle method with coagulant addition to the aeration tank
	Itako Wastewater Treatment Center	4,200	The same as above, and the modified Phoredox process
Lake Hamana	Hitomigaoka Wastewater Treatment Center	1,620	Biological phosphorus removal, and biological nitrification and denitrification by the Wuhrmann process
	Koto Wastewater Treatment Center	1,980	Same as above
Lake Biwa	Konan Chubu Wastewater Treatment Center	14,000	Nitrified Liquor recycle method with coagulant addition to the aeration tank, and the modified Phoredox process
	Okinoshima Wastewater Treatment Center	210	Batch operated oxidation ditch with coagulant addition
	Kosei Wastewater Treatment Center	5,000	Bardenpho process with coagulant addition

4.2.3 Instrumentation

One of the most advanced instrumentation technologies applied to wastewater treatment systems in Japan is the centralized supervision and distributed control system. In this system, process computers, microcontrollers (CTR), and sequence controllers (SQC) are rationally arranged so that the surveillance, data processing and supervision are executed at the control center, and the actual control is executed locally at the site.

This system has been realized as the result of advances in digital control technology applied to instrumentation, including quantitative and qualitative measuring devices, various control units, data transmission units, and data processing units. The use of this system has resulted in stable automated control, and efficient and labor-saving wastewater treatment.

Taking an example of the Kanagawa Wastewater Treatment Plant of Yokohama City, which employs this system, detailed explanation of the system will be made. The Kanagawa Treatment Plant is a relatively new treatment plant with a design capacity of 540, 000 m^3/day. The plan of the treatment plant is shown in Fig. 4.7.

(1) Configuration of the supervision and control system

The control center of this system consists of central computers installed at the control room, and microcomputers and sequence controllers distributed to each electric room.

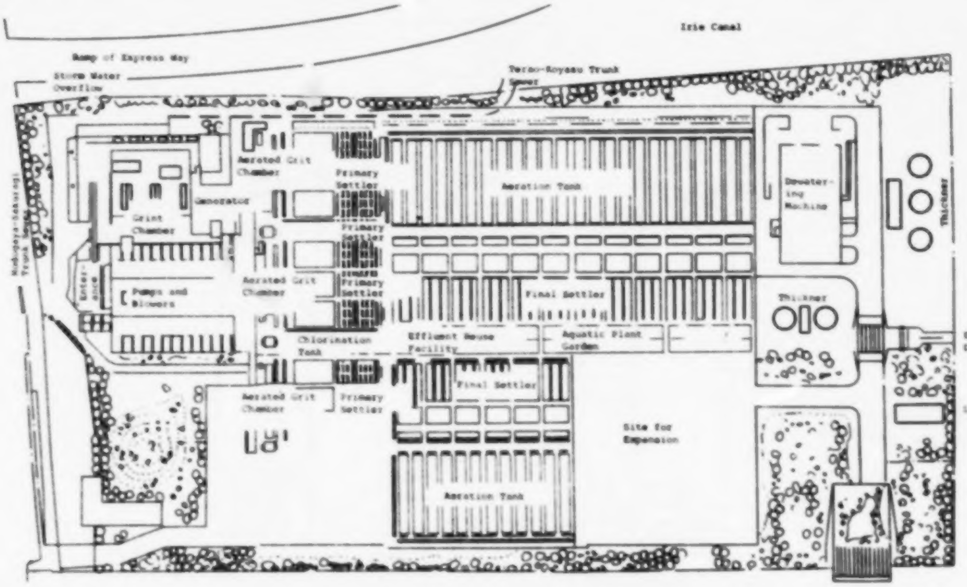

Irie Canal
Ramp of Express Way
Storm Water Overflow
Terao-Koyasu Trunk Sewer
Aerated Grit Chamber
Primary Settler
Aeration Tank
Dewatering Machine
Thickener
Irie Canal
Generator
Grit Chamber
Primary Settler
Entrance
Pumps and Blowers
Aerated Grit Chamber
Primary Settler
Final Settler
Thickener
Chlorination Tank
Effluent House Facility
Aquatic Plant Garden
Effluent Discharge
Final Settler
Aerated Grit Chamber
Primary Settler
Site for Expansion
Lodgings
Aeration Tank

Fig. 4.7 Plan of Kanagawa Sewage Treatment Plant

The complicated controls for automation are performed by the microcontrollers and sequence controllers at the local stations according to the instructions given by the central computer. The contents and results of these controls are transmitted to the central computer from remote stations for CRT display in characters and diagrams by means of the high-speed data transmission system using optical-fiber cables.

This centralized supervision and distributed control system can process an enormous amount of informations required for automated process control.

Because the supervision function and the control function are separated and work independently of each other, continuous control is possible for stable wastewater treatment operations even while the central computer is down.

Fig. 4.8 shows the system configuration.

(2) Function of the central computer system

To ensure reliability and maintainability, the central computer system employs a dual system; one is for operation and the other is a standby.

These two computers are operated by means of the load-sharing and duplex system.

The standby computer is used for off-line processing, such as preparation for the equipment management ledger and other off-line batch processing.

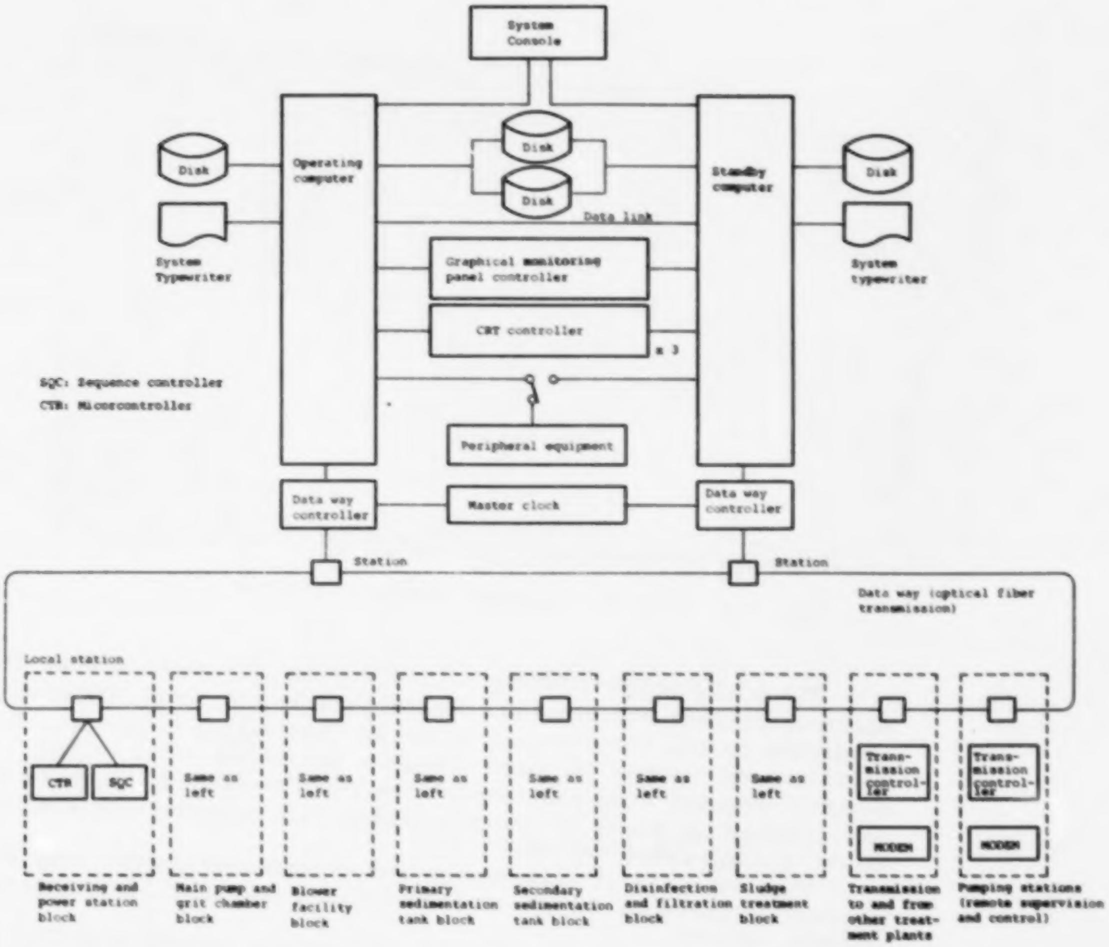

System Console
Disk
Disk
Disk
Disk
Operating computer
Standby computer
Disk
System Typewriter
Data link
System typewriter
Graphical monitoring panel controller
CRT controller
x 3
SQC: Sequence controller
CTR: Microcontroller
Peripheral equipment
Data way controller
Master clock
Data way controller
Station
Station
Data way (optical fiber transmission)
Local station
CTR
SQC
Same as left
Same as left
Same as left
Same as left
Same as left
Same as left
Trans-mission control-ler
MODEM
Trans-mission control-ler
MODEM
Receiving and power station block
Main pump and grit chamber block
Blower facility block
Primary sedimentation tank block
Secondary sedimentation tank block
Disinfection and filtration block
Sludge treatment block
Transmission to and from other treatment plants
Pumping stations (remote supervision and control)

Fig. 4.8 Schematic diagram of the centralized supervision distributed control system

The major functions of the central computer system are as follows:

(a) Supervision and operation

The system processes such information as the status of the equipments, control modes, and measured values transmitted from each local station to be displayed at a CRT and/or a graphical monitoring panel for man-machine interface.

Operators can operate the equipments, and alter the automatic control modes or predetermined values by looking at the CRT.

(b) Slips and books generating function

This system can store various process values into the files sequentially and, using these data, it can produce automatically an output on the typewriter to generate various slips and books.

(3) Functions of local stations

A local station consists of a microcontroller, a sequence controller, and a high-speed data transmission system.

Normally, these controllers perform various complex automatic controls and arithmetic controls.

The system is provided with a backup unit capable of performing the minimum required controls to ensure trouble-free operations of the wastewater treatment system even when these original controllers have failed.

Table 4.4 shows the principal control parameters. Note that those in the table to which the * mark are attached are the controls that are not regularly executed.

(4) Measuring instruments

Besides such data as water levels, flow, pressure, and air supply which are necessary to control operations, a need for collecting water quality data has increased. In this treatment plant, a PH meter is installed in the grit chamber; a sludge-density meter in the primary sedimentation tank; DO, MLSS, PH, and temperature meters in the aeration tank; and sludge density, turbidity, PH, and UV absorption meters in the secondary sedimentation tank. The readings of these meters are used as inputs for automatic control, and are stored in the computer as well as being displayed on the central CRT.

(5) Effect of the automatic controls

As mentioned, the Kanagawa wastewater treatment plant in Yokohama is a relatively large treatment plant with a design capacity of 540,000 m^3/day. By employing an automatic control system it has been possible to reduce the number of plant operators significantly. This has been especially noticeable in the number of operators in service at night and on holidays; only two operators are required to operate the whole plant including two relay pumping stations during these times.

In addition, DO control of the aeration tank makes some contribution to the reduction in operation cost. It has been found that air supply, particularly during storm period when the strength of sewage is weak, can be reduced from 20 to 30% compared with that with the flow proportional air supply strategy.

Table 4.4 List of control modes

Local station	Control device	Control mode
Extra-high tension receiving and transforming power block	1. Power-receiving equipments	1. Power failure control 2. Recovery control 3. Automatic receiving line switching control
Power station block	2. Power-distributing equipment	1. Manual pattern shifting control 2. Power factor control
	3. Generating station	1. Peak load cut control 2. Automatic starting control 3. Automatic synchronized control 4. Number of units control 5. Load transition control 6. Automatic frequency control 7. Automatic voltage control 8. Load sharing of active and reactive power control 9. Dummy load control
	4. Main pump and blower	1. Load limit control 2. Load lock control
Grit chamber and Main pump block	1. Main pump	1. Constant water level control* 2. Constant flow control* 3. Level and flow control 4. Revolutions control
Blower facility block	1. Blower	1. Constant pressure control* 2. Constant air flow control*
Primary sedimentation tank block	1. Primary sludge pump	1. Constant sludge density control* 2. Intermittent withdrawal control* 3. Continuous withdrawal control (preset control)
Aeration tank and secondary sedimentation tank block	1. Aeration	1. Constant DO control 2. Constant air flow control*
	2. Return sludge pump	1. Constant MLSS control* 2. Constant flow control 3. Constant return rate control
	3. Excess sludge pump	1. SRT control* 2. Intermittent withdrawal control* 3. Continuous with drawal control (preset control)
Disinfection and filtration block	1. Disinfection	1. Constant injection volume control* 2. Constant injection rate control
	2. Filtration	1. Inflow control 2. Number of units control

Note: Those with * mark are the control systems available as an option.

4.2.4 Control of offensive odor from wastewater treatment plants

The offensive odor prevention law was enacted in 1966. As shown in Table 4.5, eight substances generating offensive odors are presently regulated. The governers of prefectures shall determine the actual standards within the ranges of concentration listed in the Table 4.5 considering the actual situations of the local districts. These standards are applied to the concentration at a site boundary.

Table 4.5 Regulated substances under the offensive odor prevention law

Restricted materials	Range of standard (ppm)
Ammonia	1 - 5
Methyl mercaptane	0.002 - 0.1
Hydrogen sulfide	0.02 - 0.2
Methyl sulfide	0.01 - 0.2
Trimethylamine	0.005 - 0.07
Methyl disulfide	0.009 - 0.1
Acetaldehyde	0.05 - 0.5
Styrene	0.03 - 20

Note: Standards are applied to the concentrations at the boundary of the site.

Wastewater treatment plants in Japan must often be built adjacent to residential areas; therefore, attention has to be paid usually to prevent offensive odors. For this reason, measures to control offensive odors have attained significant advances. The operating wastewater treatment plant have never failed to meet the legal standards, and only a few complaints about odors have been made to wastewater treatment plants.

As shown in Table 4.6, most of the wastewater treatment plants install a cover on their main source of offensive odors, such as thickners, and the percentage of treatment plants without such a cover is only about 30%.

As shown in Table 4.7, 43% of treatment plants have odor control facilities for sludge thickners, and 57% of treatment plants have control facilities for sludge dewatering machines. Even 41% of the total treatment plants have control facilities for grit chambers which are known to generate little offensive odor. The deodorizing method most widely used is chemical scrubbing with sodium hydroxide and sodium hypochlorate, and it accounts for about half the total deodorizing facilities in use. The absorption method using activated carbon or ion exchange resin and the ozone oxidization method each accounts for only 12% of the total deodorizing facilities. The rest of the facilities almost employ highly advanced means of deodorization by combining these methods.

A representative method of this category is activated carbon absorption following acid and alkali scrubbing, or a method that combines ozone oxidation and activated carbon absorption. In some treatment plants, soil deodorizing method is used, which passes offensive odor through a soil layer. A method that induces the air with offensive odor into the aeration tank is also being applied. This method is less-costly in both construction and maintenance costs.

Table 4.6 Status of covers for wastewater treatment facilities

	Indoor		Outdoor		Percentage of uncovered facility ④/①+②+③+④
	① Covered	② Uncovered	③ Covered	④ Uncovered	
Secondary sedimentation tank	67	128	26	78	26
Sludge thickening tank	38	46	168	97	28
Dewatering machine	198	150	-	-	0

Table 4.7 Status of deodorizing facilities in Japan

	Without deodorizing facility	With deodorizing facility									Percentage of plants with deodorizing facilities (%)
		Chemical scrubbing (including water scrubbing)	Absorption	Ozonation	Others	Soil-deodorization	Introducing into an aeration tank	Masking	Combined deodorization	Sub-total	
Grit chamber	192	40	21	11	6	2	1	3	51	135	41
Sludge thickner	210	87	20	15	6	1	1	1	30	161	43
Dewatering machine	133	102	20	32	4	1	3	0	21	182	57
Total	535	229	61	58	14	4	5	4	102	478	47
Percentage (%)	-	47.9	12.8	12.1	2.9	0.8	1.0	0.8	12.3	100	-

About 12% percent of the total wastewater treatment plants in Japan have spaces which are open to the public within their premises as a park, an athletic field, or a district public meeting facility, all of which has contributed to better relations with residents living near wastewater treatment plants. Progress in odor control technology has contributed significantly to this kind of practice. In addition, when the construction of a wastewater treatment plant is undertaken, it is sometimes difficult to obtain the consent of residents near the prospective construction site. Complete control of odor, in some cases, is a key factor to get consent from nearby residents. In this sense, odor control technology has become one of the indispensable technologies relating to wastewater treatment in Japan.

5. UPGRADING OF EXISTING WASTEWATER TREATMENT PLANTS

5.1 Background

During the 100 year history of Japan's sewage works, there have been considerable changes in the socioeconomic situation that have brought more variety in the concept of planning and designing the sewarage systems. In the past, sewerage systems were only constructed at large cities where the population desity was high, and most of the wastewater treatment plants had large capacities. At present, however, the demand for wastewater treatment has increased in small and medium sized cities, and many small and medium-sized plants are being built. As to the collection system in the past, the combined sewer system was employed for the construction of sewers in large cities, but now, new sewer systems are being constructed by the separate system.

The changes in socioeconomic situation, such as people's lifestyle, concentration of population in cities, and development of industries, were very fast and large. In some cases, they were more than expected at the time of planning of the facilities. These changes have directly affected treatment plant operation, often resulting in deterioration of effluent quality.

5.2 Necessity for Upgrading of Existing Wastewater Treatment Plants

There has been a variety of causes which made upgrading of existing treatment plants necessary. Typical ones are as follows:

① Upgrading the effluent standards

Legal system concerning environmental protection was restructured and subsequently enacted around 1970, and the environmental standards on the major water bodies in Japan were then established. The importance of sewage works in controlling pollution of public water bodies was legally defined by the amendment of the Sewerage Law at that time. For almost all of the river basins, the effluent standards requiring secondary theatment were established. In some areas, more stringent standards which require better treatment than the conventional secondary treatment have been enforced based on local necessity.

② Rapid concentration of population and industrial development

Some treatment plants became overloaded because of the unexpectedly rapid concentration of population and industrial development. Especially industrial wastewater discharge often affects greatly on the operation of a treatment plant. Large variation of flow and load, and discharge of non-biodegradable organics are another problems associated with industrial wastewater. At present almost all of the municipalities have pretreatment standards, and can order industries to improve their pretreatment facilities according to its necessity. They also have surveillance systems to enforce the pretreatment standards.

③ Increase in load

The improvement of the standard of living and the change in food consumption have caused a considerable increase in pollutant load per person. Per capita BOD load used to be 35 - 40 g/cap/day in 1950's. However, it increased rapidly since then and is now about 50 - 60 g/cap/day in large cities as shown in Fig. 5-1.

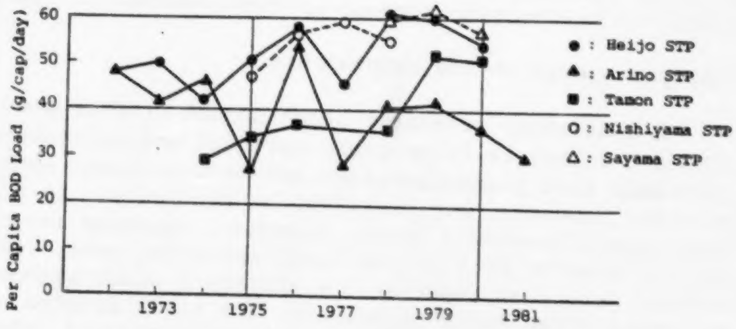


Fig. 5.1 Change in per capita BOD Load

Recent increase in organic content in sludge, which is mainly due to increase in fats and oil in sewage, has created difficult problems in sludge handling. Poor thickenability and dewaterability often required upgrading the sludge treatment facilities.

④ Revision of design criteria

The conventional design criteria were determined in reference to data obtained from large sewage treatment plants connected with combined sewer system. At a medium or small sized treatment plant of the separate sewer system based on these criteria troubles sometimes occurred even under normal loading conditions. For example, at a small treatment plant treating sewage from a housing complex, due to extremely large flow variation, sludge washout ocurrs at the time of peak flow, or sludge bulking may easily occur due to high organic loading.

The conversion of a collection system from combined to separate sewer adversely affects the sludge's settlability, compressibility, and dewaterbility, and some treatment plants have troubles in sludge handling. The treatment plant employing a separate sewer system can easily be upset by inflow and infiltration of storm water and ground water. Thus, a measure to reduce inflow and infiltration needs to be taken throughout the collection system.

⑤ Direct discharge of collected night soil into the wastewater treatment plant

There have been cases in which night soil collected from non-sewered area was directly discharged into the wastewater treatment plants at large amount, or partially treated effluent or sludge produced from the night soil treatment plants was disposed into the sewer systems. These activities often caused treatment plants to malfunction because of overloading and excessive nitrogen.

⑥ Unproper operation and maintenance

A wastewater treatment plant cannot produce good quality effluent unless it is properly operated and maintained. It is desirable that plant-operators are well-trained, employing such an operator, however, may sometimes be difficult. In a medium or small-sized treatment plant, personnel expenses may tend to account for the greater part of its total operating cost, resulting in reduced personnel expenses. A treatment plant without well-trained operators often fails to discover the early symptom of malfunction and cannot take any remedial measures to prevent deterioration of effluent quality.

⑦ Others

To attain a reduction of operational costs and efficient energy conservation the improvement of existing facilities and adequate operation and management are required.

5.3 Tentative Guideline for Upgrading of Existing Treatment Plants

The existing sewerage facilities in the greater part of sewer districts in Japan are under continuous construction and expansion. Therefore, the wastewater flows at treatment plants are continuously increasing. Consequently, almost all of treatment plants in Japan have experienced the both conditions that their treatment capabilities were temporarily too small or too large, and the personnels of these treatment plants have experienced troubles caused by these conditions. These experiences have become valuable references to the future operation & maintenance, and they have been reflected in the design of a facility in the case of expansion projects.

Although some common problems to be solved have been made clear, and the case studies and experiences for upgrading in these matters have been utilized for operations or design of other treatment facilities, seldom are the cases in which the detail of the experience and process of upgrading from idenfification of the cause of malfunction to the improvements achieved have often been disclosed to the public.

The Japan Sewage Works Agency collected information on cases concerning the causes of malfunction and improvements applied throughout the country during a six-year period from 1975 to 1981. In some cases, on-sight identifications of the causes were made and corrective steps were taken in close cooperation between the Agency and the persons in charge of the plants. The Agency also investigated to verify the effectiveness of some measures to counter the problems by using pilot and full-scale plants. A report was subsequently made by summarizing these results.

The Japan Sewage Works Association organized a committee consisting of competent engineers with an expert knowledge on the plant's management to prepare a guideline based on this report. The results were disclosed to the public as "Tentative Guideline for Upgrading of Existing Treatment Plants".

The guideline describes the causes and symptoms of troubles encountered in operation and maintenance of the activated sludge process, and explains the precautions to be taken and the methods to be employed being classified by causes.

5.4 Examples of Upgrading of Existing Plants

Among many cases in which existing treatment plants were upgraded, some representative cases are introduced in the followings.

5.4.1 Improvement in effluent quality by means of separate treatment of supernatant from the sludge treatment processes

There have been many cases in which treatment plants are suffering from loading by supernatant from the sludge treatment facilities.

The examples described below are the Toyohiragawa Treatment Plant in Sapporo City and the Senboku Sewage Treatment Plant in Sakai City, each of which has a heat treatment process for sludge treatment. Both treatment plants experienced deterioration in performance caused by high supernatant loading from sludge heat treatment process, and have been successfully improved by separate treatment of supernatant.

(1) Conditions before improvement

The strength of the supernatant generated by the heat treatment process is very high, and the following troubles occurred in the wastewater treatment facilities.

① The aeration tank became overloaded.
② The loading to the aeration tank varied largely depending on the on-off operation of the heat treatment facility.
③ The secondary effluent was colored, and an offensive odor was generated.

Besides the common problems mentioned above, the following troubles were added to the Senboku Sewage Treatment Plant.

① The treated water could not easily conform with the effluent standard (Relating to COD_{Mn}).
② The function of sludge thickening was extremely deteriorated, and solids twice as much as those in raw sewage were recirculating from sludge treatment processes.

Because of these troubles, both plants were unable to obtain the stable effluent quality.

(2) Corrective measures

As the results of detailed investigations, separate treatment process on the supernatant from sludge treatment process was taken to be the basic policy for both treatment plants.

(a) Improvement applied to the Toyohiragawa Treatment Plant

The supernatant is diluted with an equal amount of the secondary effluent, and is treated by means of the extended aeration process. The effluent from this separate treatment process is returned to the primary sedimentation tank.

In order to prevent wash-out of sludge at the secondary sedimentation tank, the weir loading was reduced and the arrangement of the weir was redesigned.

(b) Improvement applied to the Senboku Sewage Treatment Plant

The facility for treating supernatant separately has been constructed. The process was the aerobic/anaerobic biological process including biological denitrification, and the effluent is returned to the primary sedimentation tank.

(3) Plant performance after improvement

BOD, COD, and SS removals have been considerably improved after improvements at both plants, and effluent quality has come to conform with the effluent standards. Offensive odor was completely removed from the effluent.

The effect of upgrading by means of separate treatment process is summarized in Fig. 5.2.

Table 5.1 shows a comparison of the effluent qualities of the Senboku Sewage Treatment before and after the improvement.
Fig. 5.3 shows a comparison of stability of the effluent qualities; and Fig. 5.4 shows a comparison of solid mass balances before and after the improvement.

Table 5.1 Comparison of effluent qualities of the Senboku Sewage Treatment Plant

Classification	Item	BOD (mg/ℓ)	COD (mg/ℓ)	SS (mg/ℓ)
Before improvement	from Jan. to Dec. 1981	13	29	11
	from Jan. to July 1982	13	32	12
After improvement		11	26	8

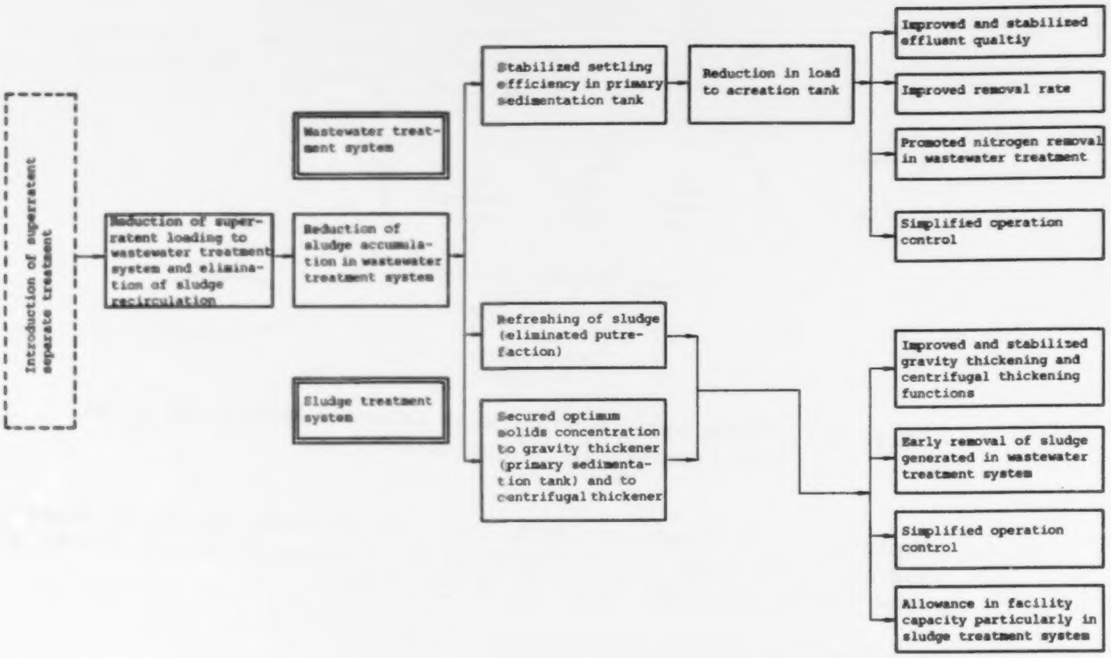
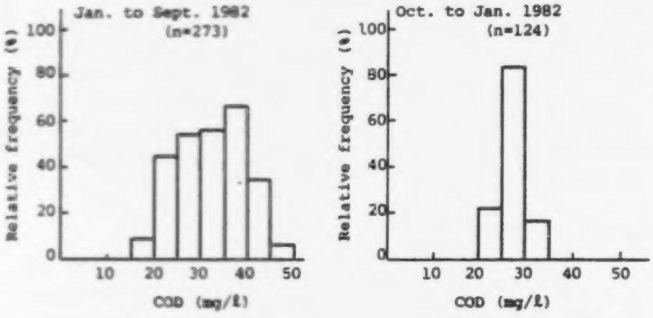

Introduction of superratent separate treatment
Reduction of superratent loading to wastewater treatment system and elimination of sludge recirculation
Wastewater treatment system
Reduction of sludge accumulation in wastewater treatment system
Sludge treatment system
Stabilized settling efficiency in primary sedimentation tank
Reduction in load to acreation tank
Improved and stabilized effluent qualtiy
Improved removal rate
Promoted nitrogen removal in wastewater treatment
Simplified operation control
Refreshing of sludge (eliminated putrefaction)
Secured optimum solids concentration to gravity thickener (primary sedimentation tank) and to centrifugal thickener
Improved and stabilized gravity thickening and centrifugal thickening functions
Early removal of sludge generated in wastewater treatment system
Simplified operation control
Allowance in facility capacity particularly in sludge treatment system

Fig. 5.2 Effects by introduction of supernatant separate treatment



Before improvement

After improvement

Fig. 5.3 Comparison of the effluent $\mathrm{COD_{Mn}}$ histograms before and after improvement

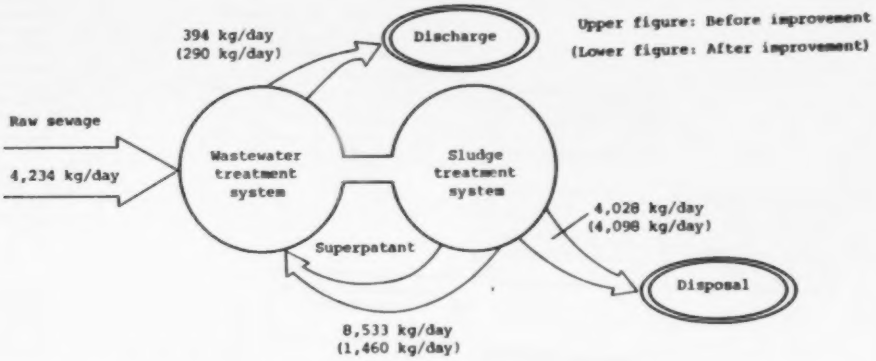

394 kg/day
(290 kg/day)
Discharge
Upper figure: Before improvement
(Lower figure: After improvement)
Raw sewage
4,234 kg/day
Wastewater treatment system
Sludge treatment system
4,028 kg/day
(4,098 kg/day)
Superpatant
Disposal
8,533 kg/day
(1,460 kg/day)

Fig. 5.4 Comparison of Solid Mass Balances before and after the Improvement in the Senboku STP

5.4.2 Improvement in Treatment Capabilities by Chemical Dosing to Primary Sedimentation Tank and by Injecting Pure Oxygen to Return Sludge at the Tobu Sewage Treatment Plant in Mitaka City

(1) Condition before improvement

This plant is of combined flow type with a design capacity of 21,000 m^3/day. Due to the increase of population in the drainage area, the volume of influent increased annually to 40% in excess of the design capacity about 30,000 m^3/day as of 1975. As a solution to this overloading condition, expansion of the treatment facility was the first consideration, however, it was practically impossible due to restrictions from location and site space. As such being the situation, this plant was taking great pains in finding effective measures for oxygen supply to the aeration tank.

(2) Corrective measures

Additional installation or rebuilding of blowers could not be chosen due to the limited budget. After studying a method to supply dissolved oxygen to the aeration tank, injection of pure oxygen into the return sludge was decided and applied after the repeated experiments on pure oxygen injection on site started in January, 1975.

The newly installed equipment for pure oxygen injection consisted of an oxygen supply unit and an oxygen dissolving unit. In the oxygen supply unit, liquid oxygen was gasified and regulated to 1.5 to 2.5 kg/cm^2 by the final pressure control valve, and then supplied to the line mixer, which was installed just after the return sludge pump.

As the second corrective measure to mitigate the load of the aeration tank, a coagulant was dosed into the sewage at the primary sedimentation tank, and thus upgraded the efficiency of primary sedimentation tank.

For this purpose, a coagulant dissolving tank and a dosing tank were provided, and a diffuser pipe was installed in the conduit to the primary sedimentation tank for mixing. Because the raw sludge production increased as a result of coagulant addition, beltpress filters were installed instead of vacum filters for sludge dewatering.

(3) Plant performance after improvement

The injection of pure oxygen has been made at a rate of 40 ℓ/min. for the amount of 5.3 m^3/min. of the return sludge. As a result, even the sewage to be treated increased from 24,000 m^3/day to 30,000 m^3/day, the effluent quality after improvement was equivalent or better than that before the improvement. Because dissolved oxygen in the aeration tank was maintained at a desirable level by increasing the oxygen supply, a stabilized effluent quality could be obtained. These results are shown in Table 5.2.

Table 5.2 Comparison effluent qualities before and after improvement, Tobu Sewage Treatment Plant, Mitaka City

Item	Flow	DO of aeration tank effluent	Effluent			
			Transparency	COD	BOD	SS
Before improvement 1975/1 - 2	23,703 m^3/day	1.65 mg/ℓ	43 cm	9.8 mg/ℓ	-	-
After improvement 1975/3 - 4	29,563 m^3/day	2.31 mg/ℓ	68 cm	11 mg/ℓ	17 mg/ℓ	25 mg/ℓ

5.4.3 Other Proposed Methods for Upgrading

The followings are the list of other methods recommended in the tentative guideline for upgrading.

(1) Corrective measures for overloading

① Improving the efficiency of the primary sedimentation tank by addition of a coagulant
② Reducing the supernatant loading by improving the performance of sludge treatment processes
③ Increase in oxygen supply by employing the improved aerator
④ Conversion from the conventional activated sludge process to the step-aeration process
⑤ Employment of the pure oxygen-activated sludge process

(2) Corrective measures for large flow variation

① To install more capacity of the equalization tank

② Utilization of the capacity of trunk sewers
③ Conversion of the primary sedimentation tank to an equalization tank

(3) Corrective measures for bulking

① Modification of the operating condition of the aeration tank
② Addition of inorganic SS to the aeration tank
③ Addition of chemical coagulant to the aeration tank
④ Employment of the anaerobic/aerobic activated sludge process
⑤ Employment of the pure oxygen-activated sludge process

(4) Improvement of the aeration tank operation

① Use of efficient aeration devices
② Automatic DO control
③ Effective use of baffle boards to prevent from short-circuit of flow
④ Reaeration of return sludge

(5) Improvement in secondary sedimentation tank to prevent wash-out of sludge

DEVELOPMENTS IN THE FIELD OF WASTE WATER TECHNOLOGY IN THE NETHERLANDS

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ABSTRACT

Recent advances in waste water treatment in the Netherlands are summarized in this paper for three major research areas of micro-pollutants, sewage sludge and innovation and upgrading of waste water purification systems.

In micro-pollutant research, the sources and amounts of organic and inorganic micro-pollutants in domestic waste water, municipal waste water with industrial contributions and direct industrial waste waters are characterized. A surprisingly large dispersion of dichloromethane was observed in the domestic wastewaters. In addition to trace metals, municipal waste waters with industrial contributions usually contain volatile chlorinated hydrocarbons, chlorophenols, hexachlorocyclohexane, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons, generally at low concentration levels. Industrial wastewaters invariably contain volatile chlorinated hydrocarbons such as tetrachloromethane and chlorophenols, especially pentachlorophenol. Removals for the various micro-pollutants are presented.

In research on sewage sludge, substantive studies on autothermal combustion, sludge thickening and dewatering, pathogenic content and disinfection, and disposal of sludge as agricultural soil conditioners and as a

substrate for trees have been completed. Raw sludge with an ash content of about 20% and dry matter content of about 25% may be burnt autothermically. Thickening can be improved by use of polyelectrolytes. Laboratory studies on sludge conditioning have characterized sludges such that practical (full-scale) improvements in dewatering are likely. The hygienic problems from the use of sewage sludge in agriculture are highly dependent on regional factors and a "safe" procedure for disposal on agricultural applications cannot be provided in general terms, each case must be assess separately.

Research on innovation and upgrading of waste water purification systems has produced novel elements, especially in anaerobic treatment. The research should stimulate potential applications of anaerobic treatment of municipal waste water using either the anaerobic sludge bed (USAB) reactors or fluidized bed technology. Industrial uses of anaerobic treatment are extensive and successful in a variety of Dutch industries. A novel approach to removing nitrite from ground water features ion exchange removal of the nitrate with biological denitrification to eliminate the nitrate and provide regenerant for the ion exchangers.

INTRODUCTION

In this report a review is given of water pollution control research currently in progress and the application of waste water treatment processes in the Netherlands. The accent is placed on advanced waste water treatment processes. Additional attention is also given to the possibilities of reducing waste water discharges by internal measures and the application of "clean technology". The research described here is mainly related to work which is still in progress or has just finished at universities, research institutes, engineering firms and industries, the results of which are publicly available. Much of the work is carried out for central or local government in the form of contract research. The work is partly paid by industry and partly by the research institutes themselves.

This report comprises three major sections:
The first section describes the problems of pollution by micro-pollutants. A great deal of research on monitoring micro-pollutants as well as research in the field of curbing this pollution has been done.

Sewage-sludge is the main-subject of the second section. There are great problems with the quality and the application of sewage sludge. In the past, most of the sludge was applied in agriculture. Over the past few years alternative applications and treatment methods have been investigated.

The third section describes the innovation and upgrading of waste water purification systems. This section reviews the developments concerning the treatment of municipal, industrial and agricultural waste waters, and contaminated ground water.

Primary sources on which this paper is based are:

- The (Dutch) journal "H_2O", mainly the volumes for the years 1982, 1983, 1984 and 1985.
- Research reports from the Dutch Ministery of Housing, Physical Planning and Environment.
- Research reports from the Governmental Institute for Sewage and Waste Water Treatment (RIZA) and several research institutes and industries.

It has to be noticed that the information in this report does not fully reflect the state of the art of water pollution control research in the Netherlands, but a serious attempt has been made to show principal developments.

MICRO-POLLUTANTS

INTRODUCTION

The legal framework for the fight against water pollution in the Netherlands has been laid down in the Pollution of the Surface Water Act which was passed on 1 December 1970. It prohibits the unlicensed discharge of polluting or harmful substances into surface water. Although considerable progress has been made in recent years, surface water pollution continues to be a serious cause for concern, and its curbing remains the chief objective of governmental policy. In the years after the Pollution of the Surface Water Act had become law, emphasis was placed on oxygen consuming substances. More recently, however, attention has primarily focused on non-oxygen consuming substances.
To this category of substances belong:

- Nutrients (phosphate and nitrate);
- Inorganic micro-pollutants (e.g. heavy metals);
- Organic micro-pollutants (e.g. persistent pesticides and PCB's).

The name micro-pollutants is used because the concentrations at which these substances may cause harmful effects are at the level of micrograms and even nanograms per liter. In cases of oxygen consuming substances the concentration levels amount to tens of milligrams per liter.

In this chapter the results are given of a number of research projects in the field of inorganic and organic micro-pollutants.

SOURCES OF ORGANIC MICRO-POLLUTANTS

Organic micro-pollutants in domestic waste water

In 1984 the Governmental Institute for Sewage and Waste Water Treatment carried out an initial study on the presence of a number of organic micro-pollutants in domestic waste water. Waste water of five residential areas was sampled and analysed. The waste water streams contained neither rain-water nor industrial waste water. The results of the study are given in Table 1.

The enormous dispersion in the figures for dichloromethane is especially striking and its causes are still unclear. The study will be continued.

TABLE 1. ORGANIC MICROPOLLUTANTS IN DOMESTIC WASTE WATER[7]
(in mg/inhabitant/year)

Compound	Amsterdam[1]			Steenwijk[2]			Enschede(I)[1]			Enschede(II)[1]			Maarssen[2]			MEAN[3]
	min.	max.	mean	min.	max.	mean	min.	max.	mean	min.	max.	mean	min.	max.	mean	
dichloromethane	157	80000	9000	400	39010[3]	12410[3]	0	110	40	0	92000	15000	73	383	256	24600
trichloromethane	84	204	150	146	285	190	48	139	102	58	325	200	820	1570	1130	303
tetrachloromethane	0[6]	296	88	146	402	157			0	0	270	80	0	606	223	102
trichloroethene	0	394	40			0	0	139	51			0			0	18
1,2-dichloropropene																
tetrachloroethene			0			0	0	2835	686	0	172	29			0	106
1,2 dichloroethane			0			0			0	0	157	15			0	4,0
1,1,1-trichloroethane																
monochlorobenzene	0	299	29			0			0			0			0	8,4
1,2-dichlorobenzene			0			0	0	139	28	0	270	120			0	40
1,4-dichlorobenzene	212	1680	647	84	281	197	869	1830	1190	0	2770	836	1350	4590	2960	1040
hexachlorobenzene	0	0,8	0,15	0	0,8	0,32			0	0	0,51	0,04	0,91	1,5	1,1	0,26
α-hexachlorocyclohexane	0,8	2,1	0,31	0	0,4	0,07	0	0,91	0,4	0	1,1	0,58	1,3	3,5	2,1	0,91
γ-hexachlorocyclohexane	5,5	77	21	6,2	26	15	1,4	3,5	2,0	1,0	4,0	2,7	3,6	7,7	5,5	12,8
2,4,5-trichlorophenol			0			0	0	28	8,4			0			0	1,1
2,4,6-trichlorophenol	2,1	4,4	6,2	3,7	4,7	4,0	2,3	14	6,2	2,7	16	7,3	4,4	9,5	7,7	6,6
2,3,4,5-tetrachlorophenol			0			0			0	0	7,7	0,7			0	0,2
2,3,4,6-tetrachlorophenol	4,4	11	6,9	3,7	4,7	4,0	8,4	32	14	0	27	5,8	28	139	53	14
pentachlorophenol	10,2	36	23	12	33	20	18	51	35	12	439	77			0	36
polychlorinated biphenyls	0	3,4	0,73	0	2,2	0,9			0			0			0	0,32
polycyclic aromatic hydrocarbons[5]	13	27	21	6,9	1,6	11	18	68	20	6,2	18	13	2,3	16	11	16

[1] number of samples: 10

[2] number of samples: 5

[3] average over 35 samples

[4] sum of PCB 8,52,101,138,153 and 180

[5] sum of fluoranthene, benzo(6)fluoranthene, (benzo(k)fluoranthene, benzo(a)pyrene, benzo(g,h,i), perylene and indeno(1,2,3-c,d)pyrene

[6] zero means concentration below detection limit

[7] in all samples below detection limits:
1,3-dichloropropane
1,1,2-trichloroethane
1,2,3-trichloropropane
1,2,3-trichlorobenzene
1,2,4-trichlorobenzene
1,3,5-trichlorobenzene
β-hexachlorocyclohexane

Organic micro-pollutants in municipal waste water treatment plants

In 1983 the Governmental Institute for Sewage and Waste Water Treatment (RIZA) studied the presence of organic micro-pollutants in influent, effluent and sewage sludge of six municipal waste water treatment plants.

The results of the study were published and presented at the IAWPRC-congress of Amsterdam in September 1984. The conclusions of the study are:
The conclusions of the study are:

- Volatile chlorinated hydrocarbons in sewage appear to originate mostly from industrial emissions. The amount of the emissions may fluctuate considerably, especially in the case of dichloromethane and 1,2-dichloroethane.
- Chlorophenols, hexachlorocyclohexane, polychlorinated biphenyls (PCB) and polycyclic aromatic hydrocarbons are - on a low basic level - invariably present in municipal waste water and in many industrial waste water streams.
- In addition to point sources there are also diffuse sources such as deposit from the air and road traffic, which are responsible for the extra sewage pollution. In the study this is demonstrated especially in the case of polycyclic aromatic hydrocarbons.
- PCB and fluoranthene are invariably detected in sewage sludge. Occasionally hexachlorobenzene, 2,4,5-trichlorophenol, 2,3,4,6-tetrachlorophenol, pentachlorophenol and benzo(b)fluoranthane were also present.
  In the study it has not been possible to give a full assessment of the fate of these substances in a treatment plant. More intensive research will be initiated for that purpose.
- The overall removal in the municipal treatment plants amounts to:

. volatile chlorinated hydrocarbons	50-90%
. hexachlorobenzene	95%
. hexachlorocyclohexanes	40-65%
. chlorophenols	20-40%
. PCB	about 90%
. polycyclic aromatic hydrocarbons	85-95%

Organic micro-pollutants in industrial waste water

Since 1980 RIZA has been researching the presence of organic micro-pollutants in industrial waste water (1). In 1983 waste water of 37 industries was examined for the presence of:

- Heavy metals
- Drins (e.g. aldrin)
- Polychlorinated biphenyls
- Chlorophenols
- Benzene and chlorinated benzenes
- Tri- and tetrachloromethane.

The overriding conclusion was that components such as pentachlorophenols are present in most waste waters. Even in brewery waste water. In this particular case the waste water became "polluted" because of the glue on the beer-bottle labels.

Table 2 shows that a large number of components are present in the various waste water streams. It has not yet become clear why these components are present in most cases. Consequently, research is continuing.

TABLE 2. SURVEY OF THE PRESENCE OF HAZARDOUS SUBSTANCES IN INDUSTRIAL WASTE WATER FROM DIFFERENT INDUSTRIES

substance / branch of industry (number of plants measured)	trichloromethane	tetrachloromethane	2,4,6-trichlorophenol	pentachlorophenol	hexachlorobenzene	polychlorinated biphenyls *)
slaughtery (2)	+	+	+	+	+	-
dairy products (3)	+	+	+	+	+	-
fruit and vegetables (1)	+	+	+	+	-	-
margarine and fats (2)	0	+	0	+	+	+
sugar (1)	0	+	0	0	-	-
soft drinks and carbonated waters (1)	+	+	+	+	-	-
brewery (1)	0	+	+	+	-	-
textile (2)	+	+	+	+	+	+
leather (2)	0	+	+	+	-	-
paper, pulp and paperboard (2)	+	+	+	+	-	0
wood-impregnation (2)	0	+	0	+	0	0
printing (1)	0	0	0	+	0	0
painting (2)	0	+	+	+	+	-
soap and cleaning (detergent) preparations (1)	+	+	0	+	0	+
rubber (2)	+	+	0	+	+	+
dye (3)	+	+	+	+	+	+
electroplating (4)	0	+	+	+	+	-
photographic laboratory (1)	-	+	0	+	+	-
laundry (1)	+	+	+	+	+	-
motor-overhaul (1)	0	+	0	+	0	+
hospital (1)	+	+	+	+	+	-
incineration of refuse (1)	0	+	0	+	0	0

+ = present in waste water
- = undetected in waste water
0 = research has not finished, no positive results thus far
*) = (probably) one or more of the isomers: PCB 28, 52, 101, 138, 153 and 180

Polycyclic aromatic hydrocarbons

In 1984 Hoogovens IJmuiden installed two precoat-vacuumfilters - each with a filter surface of 36 m^2 - for the removal of polycyclic aromatic hydrocarbons (PAH). The amount of waste water to be processed is 120 m^3/hr. PAH-emission has been reduced from 15 to less than 1 kg/day. The costs of investment of the filters were 1.7 million Dutch guilders. Total investments, constructional and electrotechnical supply included, amounted to 3.1 million Dutch guilders.

PAH are among other components caused by pyrolysis of organic material such as occurs in the coke oven process. A coking-plant produces coke by heating coal, air-free, to a temperature of about 1300 °C. The volatile substances released in the process are called coke oven gas and are used in the production plant.

Before use the gas has to be cooled and purified. In this process waste water containing PAH and other substances is produced.

Analyses show that PAH is generally present in - or on the surface of - suspended solids in the waste water (Table 3).

TABLE 3. PAH IN WASTE WATER (IN µG/L)

	liquid	suspended solids
naphthalene	n.d.	n.d.
acenaphthene	n.d.	n.d.
dibenzfurane	n.d.	5
fluorene	2	5
fenanthrene + anthracene	30	185
fluoranthene	15	405
pyrene	6	205
1,2-benzanthracene + chrysene	1	280
benz(b+j+k)fluoranthene	n.d.	120
(1,2+3,4)benzpyrene	n.d.	155
1,12 benzperylene	n.d.	60
coronene	n.d.	35
total	54	1470

n.d. = non-detectable (< 1 µg/l)

For the removal of PAH a particular filtration method has been chosen. Precoat filtration gives the best environmental and economical results (Table 4).

TABLE 4. RESULTS PILOT-PRECOAT FILTER. (PAH IN μG/L)

	infl.	effl.	infl.	effl.	infl.	effl.
naphthalene	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
acenaphthene	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
dibenzfurane	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
fluorene	n.d.	n.d.	7	n.d.	n.d.	n.d.
fenanthrene + anthracene	65	5	225	10	10	15
fluoranthene	487	4	1435	8	370	20
pyrene	448	n.d.	1093	n.d.	356	7
1,2-dibenzanthracene + chrysene	873	15	2660	4	1190	4
benz(b+j+k)fluoranthene	755	n.d.	1315	n.d.	440	n.d.
1,2-3,4 benzpyrene	965	n.d.	1180	n.d.	520	n.d.
1,12-benzperylene	160	n.d.	240	n.d.	70	n.d.
total	3753	24	8155	22	2956	46
dissolved	13	24	38	22	41	46
adsorbed	3740	n.d.	8117	n.d.	2915	n.d.
removal percentage (%)	99,4		99,7		98,4	

n.d. = non-detectable (< 1 μg/l)

It should be noticed that a biological treatment process has been inplemented - following filtration -to remove other components. The biological treatment process will effect a further reduction in the concentration of PAH (2).

Volatile chlorinated hydrocarbons and dioxines

In the beginning of 1985 the pesticides factory Duphar (Amsterdam) realized the second phase of its scheme for waste water purification.

The first phase uses filtration and a steam-stripper for the removal of suspended solids and volatile chlorinated hydrocarbons such as tetrachloromethane, trichloromethane and monochlorobenzene. This phase has been in operation since the spring of 1984. The application of a filtration step also reduces the emission of dioxines and dibenzofuranes considerably to values below the detection limit (25 ng/l). This emission amounted to 40 g a year.

Filtration consists of four steps: coarse filter, gravel filter and two close grained anthracite filters. Steam-stripping reduces the concentration of volatile solvents from 210 to less than 10 mg/l; a removal efficiency of more than 95%. The emission of these substances amounted to 33,000 kg a year.

The second phase, activated carbon adsorption, is meant to remove non-volatile, adsorbable chlorinated hydrocarbons. Two columns in series are used. The activated carbon is regenerated by a thermal method. The content of adsorbable compounds in the waste water is reduced from 160 to less than 10 mg/l. The emission amounted to 25,000 kg/year. Total costs of investment are in excess of ten millions of Dutch guilders. The annual exploitation involves several millions of Dutch guilders.

Duphar is also taking part in research on the disintegration of organic chlorinated compounds through thermolysis with hydrogen. This "hydrodechlorination process" is a discovery of the University of Leiden, which University is developing the process in co-operation with Kinetics Technology International (KTI) of Zoetermeer.

Thermal hydrodechlorination may be an effective method in eliminating dioxines. Duphar's initial research is scheduled to finish early in 1986 (3,4).

Volatile chlorinated hydrocarbons and hexachlorinated compounds

AKZO Zout Chemie (Delfzijl) is investing several millions of Dutch guilders in the construction of a treatment plant for the removal of volatile chlorinated hydrocarbons such as tetrachloroethylene and tetrachloromethane and hexachlorinated compounds.

The volatile compounds are removed from waste water by the use of a stripper. The current emission comes to at least 16,500 kg/year. The removal of hexachlorinated compounds occurs through sedimentation, its costs of investment will amount to two million Dutch guilders.

Hexachlorobenzene, -butadiene and -ethane are byproducts of solvents. Most of the compounds (99,9%) are separated, collected in drums and sent to salt mines in W-Germany. The discharge of about 60 kg of hexachlorinated compounds a year and the pollution of the sediment through this emission will soon belong to the past (5).

Phenoxy acetic acids and chlorinated cresols

AKZO Zout Chemie (Rotterdam) intends to construct a waste water treatment plant to process waste water from the pesticides plant and the vinylchloride plant. The new treatment process consists of an activated sludge plant with activated carbon dosing (PACT-process). The treatment plant is due to come into operation in January 1987 and will cost 15.5 million Dutch guilders.

The pesticides plant produces phenoxy acetic acids (MCPA and MCPP). The plant's waste water contains these acids as well as chlorinated cresols. The annual emission of these substances comes to 6600 kg.

Using the foregoingly mentioned treatment process the governmental demand for a concentration of less than 1 mg/l of the cited substances in the waste water may be met. This is comparable with a maximum emission of 1650 kg/year.

In cases of peak loads of chlorinated aromates, the waste water is pretreated with hydrogen peroxide. Additional process-integrated measures have also been taken.

Instead of the use of activated carbon, resin-adsorption with Amberlite XAD-4 was taken into consideration as a pretreatment. Its execution would prove to be successful. Higher costs of investment have resulted in the selection of the PACT-process. The waste water of the vinylchloride-plant is pretreated by steamstripping, precipitation and sodiumsulphite dosing. Ethylenedichloride, copper and chlorine concentrations are reduced below 1 mg/l.

The treatment plant must have a capacity of 70 m^3 of waste water per hour. The volume of the aeration tank amounts to 3800 m^3 (6).

INORGANIC MICRO-POLLUTANTS

Sources of inorganic micro-pollutants

In 1984 the presence of arsenic and heavy metals in domestic waste water was studied. Domestic waste water - unmixed with rainwater or industrial waste water - of seven residential areas was sampled and analysed four times. The results are given in Tables 5 and 6. The annual sum of the average quantity of arsenic and heavy metals is 16.5 grams per inhabitant.

A study of this nature has never previously been executed in the Netherlands. Calculations on the basis of literature data have been used thus far (7).

TABLE 5. ARSENIC AND HEAVY METALS IN DOMESTIC WASTE WATER (CONCENTRATIONS IN µG/L)

Location	Zn	Cu	Pb	Ni	Cr	As	Cd	Hg
Amsterdam								
- Meijehof	168	166	15	11	5	4	1.5	0.7
- Nieuwlandhof	143	244	13	13	4	3	1.3	0.6
Enschede								
- Stokhorst	172	139	22	9	5	4	1.0	0.6
- Stroïnkslanden	155	127	18	10	4	4	1.0	0.3
Maarssen	212	149	18	6	4	4	1.8	0.2
Steenwijk	195	33	28	13	4	3	1.3	0.3
Vught	146	96	15	9	4	4	0.6	0.3

TABLE 6. ARSENIC AND HEAVY METALS IN DOMESTIC WASTE WATER (G/INHABITANT/YEAR)

Location	Zn	Cu	Pb	Ni	Cr	As	Cd	Hg
Amsterdam								
- Meijehof	7.2	7.1	0.6	0.5	0.2	0.2	0.05	0.03
- Nieuwlandhof	6.5	11.1	0.6	0.6	0.2	0.1	0.06	0.03
Enschede								
- Stokhorst	7.6	6.2	1.0	0.4	0.2	0.2	0.04	0.03
- Stroïnkslanden	8.9	7.3	1.0	0.6	0.2	0.2	0.05	0.02
Maarssen	10.1	7.1	0.9	0.3	0.2	0.2	0.09	0.01
Steenwijk	8.7	1.5	1.2	0.6	0.2	0.1	0.06	0.01
Vught	7.5	4.9	0.8	0.5	0.2	0.2	0.03	0.02
Median	7.5	7.1	0.9	0.5	0.2	0.2	0.05	0.02
Mean	8.1	6.5	0.9	0.5	0.2	0.2	0.05	0.02

The environmental problems of heavy metals focus especially on the pollution of subaquatic soils, the consequences for organisms in water and sediments and the pollution of sewage sludge. Heavy metals in surface water are for a considerable part (75% as an average) attached to suspended solids.

Reduction in the emission of inorganic pollutants

The solution to the heavy metal problem has to be found in the fight with the pollution source, aimed at reducing the pollution. In principle, two ways are open: process alteration and waste water purification.

To prevent polluting substances from originating by applying less polluting production processes is of main interest where the fight against water pollution by heavy metals is concerned. Two, so-called clean technology processes are: the use of a new, blue passivating-bath and the substitution of cadmium by galvano-aluminium.

The first process - developed by TNO - consists of a blue passivating technique without nitric acid or nitrate-ions, with substitution of chromic-acid by the less agressive potassium chromium sulfate. When this process is applied, savings are especially made in the field of reducing costs of waste water treatment. The process control at varying product supplies remains a restriction, rendering it as yet only suitable for the treatment of one constant product.

The second clean-technology-process, the substitution of cadmium by aluminium, has been developed by the electroplating industry of Hegin Galvano Aluminium in co-operation with the German Siemens Company. The process consists of the electrolytic precipitation of aluminium at a temperature of about 100 °C in an organic electrolyte, excluding water and air, and it precludes pollution of water or air. The process has been successfully tested in a so-called "rack" machine (parts placed on racks), which is already on the market.

When choosing a purification plant, a distinction may be made between systems for the treatment of the total waste water flow and systems for partial treatment. Systems belonging to the first category are precipitation, detoxification, neutralization, de-watering (ONO) and ion exchange. These systems are extensively applied in the electroplating industry. By applying process integrated techniques or provisions for treatment of reaches of streams which contain heavy metals, the metals in question may be re-used in principle. A couple of process integrated systems which are being developed appear to offer fair prospects. They concern the removal and the recuperation of heavy metals from waste water with the aid of membrane filtration and the electrolytic recuperation of heavy metals from diluted solutions. Hyperfiltration (reverse osmosis) can be applied on separate rinsing water streams as well as on the total waste water flow. With regard to a number of types of rinsing water, especially those originating from nickel baths, the treatment by means of hyperfiltration offers economic advantages.

An investigation into the applicability of electrolysis for the removal and recuperation of nickel and zinc from rinsing tanks in the plating industry is carried out by TAUW, TNO and Magneto Chemie. Thus far, application of electrolysis mostly takes place when precious metals have to be removed.

Finally, in the field of heavy metal removal, a number of recent developments may be mentioned, namely the recuperation of metal by means of fluidized bed crystallization and the removal of metal (Cd) with the aid of bacterial processes.

Further activities in the field of metal removal will give priority to process integrated provisions. The further development of the membrane technology and the electrolysis are also expected to gain more attention (8).

SEWAGE SLUDGE

When municipal sewage water (a combination of domestic and industrial waste water) is treated, sludge containing heavy metals developes. The level of heavy metals in sewage sludge has decreased considerably during the past few years due to reorganizations in industry. The decrease for nickel, cadmium and mercury amounted to 50% or more in the period 1976-1980. The copper and lead content decreased by 30%, while the chromium content decreased by 20%. At present the heavy metal contents are on average below the limits set for direct agricultural use. However, it does not mean that every quantity of sludge necessarily satisfies the limit. From the sludge that was deposited in agriculture in 1981 only 42% satisfied the limit.

Notwithstanding the observed opposition against combustion, an increasing interest in sludge combustion as a sludge processing method may be noticed in the Netherlands. The opposition against combustion is especially based upon the supposed environmental objections and the heavy costs. The increasing interest in combustion is expressed by an intensification in combustion research. However, the interest has not yet produced an expansion of the number of combustion plants. The preference for the fluidized bed combustion system is remarkable in this context.

Within the scope of study and research much attention has been given to the problem of energy, because this item is of major interest with regard to capacity and costs of combustion. It is important that the sludge may be burnt autothermically (energetic equilibrium). Important factors in this respect are the dry matter content of the sludge and the ash content of the dry matter. Based upon energetic equilibrium, the mutual relation between these factors has been worked out in Figure 1.

From the above it appears that - roughly speaking - raw sludge with an ash content of 20% and a dry matter content of 25% (heat of combustion equals 23 MJ/kg of organic material) may be burnt autothermically. This type of relation, based upon the thermal balance, may be a useful expedient when application of sludge combustion is considered. It is possible to check the degree of de-watering necessary for autothermal combustion and/or to check whether the required degree of de-watering is feasible in technical terms. Combustion of sludge becomes expensive when additional fuel has to be added. In these cases the capacity of the combustion plant decreases, while extra energy has to be added. It can be stated in general that new developments in the field of de-watering, resulting in higher dry matter contents and improvement of energy-efficiency of the combustion process may take combustion closer within the range of sludge processing methods (9,10).

Within the scope of an investigation into sludge combustion, carried out in a fluidized bed incinerator (inner diameter 0.5 m, total height 5 m), attention has been given to the energy balance as well as to the environmental aspects of the combustion process. In this investigation long-term experiments (52 hours) were carried out with de-watered sewage sludge (14% dry matter) under the following conditions: sludge output 100 kg/hr, temperature of the bed 825 °C,

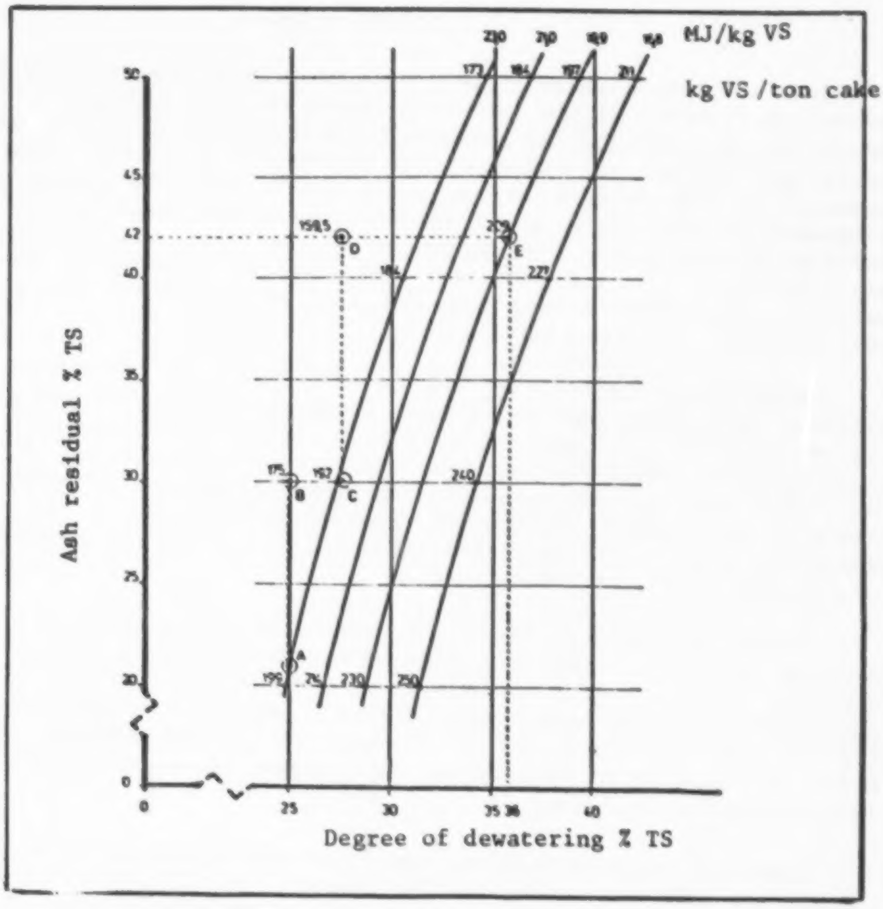

Figure 1. Autothermal combustion. Thermal efficiency of incinerator 70%.

excess air 20% and static height of the bed 0.55 m. The composition of the flue-gases was as follows: O_2 3.5% by volume, CO_2 11.4%, CO 78 mg/Nm³, NO_x 348 mg/Nm³, C_xH_y 14 mg/Nm³ and SO_2 923 mg/Nm³. By applying a cyclone and a cloth filter, heavy metals remained (about 98%) in the solid residue. In other words, about 2% of the heavy metals disappears into the atmosphere. Fluidized bed combustion may be an attractive treatment method for sewage sludge. Test runs are required to realize a well-made design for a full scale combustion plant plant (11,12).

Within the scope of sludge thickening and de-watering the following developments can be mentioned.

From research it has appeared that the thickening of digested sludge may be improved upon the addition of a polyelectrolyte. The mixing of polyelectrolyte and sludge appears to be of vital importance in this process. A relatively low amount of polyelectrolyte is applied to improve the thickening. The polyelectrolyte present in the water phase must be dispersed uniformly over the the sludge particles. However, excessive mixing must not occur, to avoid destroying the formed sludge flocks. By means of experiments at a sewage treatment plant a correct mixing between polyelectrolyte and sludge has been obtained. Using a polyelectrolyte dosing (Praestol 423 K) of 2.5 g/kg of dry matter, the dry matter content - after thickening - was increased from 3% to almost 6%. This signifies a reduction in the sludge volume that has to be disposed of (13).

An investigation has been carried out into optimization of the conditioning of sewage sludge with inorganic chemicals in relation to sludge handling with filter presses. In 1982 twelve municipal sewage treatment plants in the Netherlands were equipped with filter presses, with a total processing capacity of 4.2 million population equivalents (p.e.). The sludge of about 3.3 million p.e.'s is conditioned with inorganic chemicals. This involves an amount of money for chemicals of about 3.5 million Dutch guilders. Even a minor reduction in chemical consumption will result in considerable savings on running costs.

An investigation has been carried out into simple tests for conditioning on a laboratory scale, a method which can also be used to characterize the sludge. A standard mixer in an experimental set-up of 1 liter appears to work well. After adding $FeCl_3$, 15 seconds of mixing at a speed of 1000 rpm is required; after adding $Ca(OH)_2$, 60 seconds at 500 rpm is required. With this set-up and method of conditioning, characterization of sludge becomes possible. For that purpose, conditioning tests at 2.5, 5, 7.5 and 10% $FeCl_3$ by weight and 10, 20, 40 and 60% $Ca(OH)_2$ by weight, based on dry matter are carried out, whereupon pH-value, suction time and MFT[1]-dry matter are determined. After these tests combinations of $FeCl_3$ and $Ca(OH)_2$ are selected, which simultaneously satisfy the following conditions: pH $\geqq$ 12, suction time $\leqq$ 100 seconds and MFT-dry matter $\geqq$ 21% of dry matter. Close agreement appears to exist between the results of the laboratory experiments and the practical (full-scale) results. The developed test method is also suitable for checking whether other conditioning chemicals e.g. $AlCl_3$ instead of $FeCl_3$, or waste lime are suitable for the chemical conditioning of a specific type of sludge (14).

An other aspect of sewage sludge permanently drawing attention is the further processing and disposal of the sludge. For the benefit of the application of sludge in agriculture, attention has been given to the hygienic aspects of this particular application. Pathogenic bacteria such as *Salmonella, Clostridium botulinum, Taenia saginata, Ascaris lumbricoides, Escherichia coli, Campylobacter jejuni, Toxoplasma gondii, Sarcocystis spp* and viruses have the potential to spread by sewage sludge. With regard to pathogenic bacteria three ways of restriction may be recognized:

- Restriction of the application of sewage sludge (in the production of crops for human consumption);
- Restriction of the use of land following application of sewage sludge (to institute waiting times);
- Disinfection of sewage sludge.

---

[1] MFT = Modified Filtration Test.

Disinfection processes may be divided into a group which has disinfection as its primary target (pasteurization, irradiation) and a group in which stabilization is the primary aim, but in which proper dimensioning can also realize adequate disinfection (aerobic thermophilic stabilization, composting and stabilization with lime). The hygienic problems of the application of sewage sludge in agriculture are complex and highly dependent on regional factors. This leads to the conclusion that a "safe" procedure cannot be indicated in general terms, and each case has to be assessed separately (15).

It has been verified to which extend the forests, which take up eight percent of Dutch soil area, can contribute to the disposal of sewage sludge. Some aspects have been investigated, such as sewage sludge in existing forests, sewage sludge as soil conditioner and sewage sludge as a substrate for trees. Research has led to the conclusions that sewage sludge is a material of widely varying composition and qualities, which may alter considerably in the course of time (flushing of lime, degradation of organic substances) and that therefore planting advice for dumping sites for sewage sludge can only be given conditionally. The necessity for planting research on sewage sludge of various origins remains. Dutch forests offer hardly any potential at all for the disposal of sewage sludge (16).

INNOVATION AND UPGRADING OF WASTE WATER PURIFICATION SYSTEMS

MUNICIPAL WASTE WATER

In the past few years the technology for the purification of municipal waste water is strongly developing in the Netherlands. Novel techniques are increasingly being used.

Biological dephosphating constitutes an important development in this field. Its has been proven that biological dephosphating is also a suitable method for removing phosphate at moderate temperatures. An important fact - when using this technique -is that it makes the removal of the phosphate possible in such a way that the removed phosphate is regained in a very pure form.

In the past five years a great deal of research has been done on the potential use of Nitrilotriaceticacid (NTA) in detergents. The biodegradability of NTA and also the influence of NTA on the binding of heavy metals to the sewage sludge have been researched.

The research has been done on laboratory-scale (batch) and on pilot-plant scale (continuous-system). The content of NTA in the waste water amounted to 20-40 g/m³ (as free acid H_3NTA). This content is expected whenever NTA is used on a large scale.

It has been proven that NTA has no adverse effects on the metal "household" of the activated sludge system when it has become completely degraded. When this is not the case, the introduction of NTA is thought to give a higher effluent load, especially of the metals nickel, zinc and lead in the activated sludge process (17).

Two cases have been investigated: an activated sludge plant with low sludge load and an activated sludge plant with high sludge load.

The investigation of the plant with the low sludge load (0.13 kg BOD/kg. dry mater per day) resulted in the following conclusions:

- The adaptation to 10 g of NTA/m^3 takes three days. From literature it appeared that many researchers experienced adaptation times of two weeks.
- After adaptation NTA degradates very well. Even a strong changing influent flow does not have adverse effects on the degradation of NTA.
- The degradation of NTA decreases greatly when the temperature falls. Below 7 °C the degradation becomes very poor, a fact confirmed by literature references.
- The bio-degradation of NTA is especially sensitive to interruptions in the degradation process of the total amount of organic materials. A disturbance of the process, for instance a decrease in the COD-degradation from 95% to 80%, will result in a decrease in degradation of the NTA of up to 60%. When the COD-degradation drops to 60%, the degradation of NTA stops completely. Recovery of the COD-degradation is much faster than recovery of the NTA-degradation (18).

The investigation of the plant with the high sludge loading (0.4-0.8 kg BOD/kg dry matter per day) resulted in the following conclusions:

- The degradation of NTA takes more time when the sludge load is higher and the sludge age is lower.
- The degradation of NTA is poor when the plant is overloaded or when there is a disturbance in the COD-degradation.
- At temperatures below 7 °C, the NTA-degradation decreases greatly.
- NTA is degrading very well during periods of non-disturbance (at sludge loadings of 0.13-0.41 kg BOD/kg dry matter per day). This is even the case when the NTA-content of the waste water is varying widely.
- When the NTA content remains constant adequate degradation occurs, also at sludge loads of 0.83 kg BOD/kg dry solids per day. There are problems with the NTA-degradation when the NTA-content varies.

The overall conclusion must be that adequate degradation will occur in an activated sludge system when:

- The sludge load is beyond 0.4 kg BOD/kg dry solids per day;
- There is no strong change in NTA-contents;
- There are no disturbances during the purification proces;
- The temperature is not lower than 7°C (19).

Similar research has been done on three types of purification plants. They were an oxidation ditch, an activated sludge system and a trickling filter. The research concludes that a content of 20 mg of NTA/l degrades completely in an oxidation ditch and in an activated sludge system. In cases of trickling filters the degradation will not be above 75%. None of the plants produced increased transportation of heavy metals. When the NTA content is 40 mg/l, great differences in degradation will occur because of the type of plant and the time of year. When the degradation of NTA is poor, chances of increased metal-transport activities are higher and sensitivity to peak loads is higher. The presence of NTA in the influent does not interfere with the biological activity of above mentioned plants (20).

Novel elements in the field of waste water treatment in the Netherlands mainly deal with anaerobic treatment. Scientists have succeeded in getting a high sludge content inside the reactor. This high sludge content in the Upflow Anaerobic Sludge Blanket (UASB) reactor is caused by the development of granular sludge in the reactor. This particular sludge has a high settling velocity. In filter- and fluidized bed reactors the sludge is fixed to supporting media.

In the past few years a great deal of research has been done to stimulate the application of anaerobic treatment of municipal waste water. A full-scale plant is expected to be built in 1986. In this plant municipal waste water will be treated before it is sent to an aerobic plant.

Haskoning, a Dutch engineering consultancy has done research - together with the Agricultural University of Wageningen - on the treatment of municipal waste water in Colombia. Thus far results have been outstanding. The opinion is that the success of this research will stimulate the application of anaerobic treatment in moderate temperature regions too (21).

At the Technological University of Delft a process-model of a methane-reactor has been constructed. This model will improve the control of the system (22).

Another perspective constitutes the use of the fluidized-bed technology. This type of anaerobic treatment is already operating on full-scale for the treatment of industrial waste water (23).

The major problem of the future will constitute the application of sewage sludge. This problem has both quantitative and qualitative aspects. Currently the greater part of the sludge is put to agricultural use. Because an excess of fertilizer is already available, this application becomes more and more of a problem and the quality requirements become increasingly demanding. The major demands are in the field of the heavy metal content of the sludge. It has to be expected that in the future demands will also be introduced with regard to the content of organic pollutants. To reduce its quantity, research is in progress on thermophilic digestion.

It is expected that within 15-30 years a great deal of waste water treatment plants will have to be partially or totally renewed. On that moment investments will have to be made to fulfil future environmental demands. Noise, odour, effluent quality come to mind. The financial aspects are naturally very important (exploitation, costs of investment).

At TNO and the engineering consultancy of Witteveen en Bos, a feasibility-study is in progress aimed at coming up with an answer to the question of renovation. The study is required to give the correct answer to the above-mentioned question. and will be completed in 1985 (24).

INDUSTRIAL WASTE WATER

Abattoirs and slaughter-houses

The Dutch engineering consultancy Technisch Adviesbureau voor de Unie van Waterschappen (TAUW) has developed a complete waste water purification system for the waste water from slaughter-houses.

The system (Figure 2) consists of an anaerobic treatment step (UASB-reactor) followed by an aerobic treatment step (biorotor). Thus far many problems have occurred. The major problem was the passage of sludge - from the biorotors used -by suspended materials. Owing to the presence of suspended materials no granular sludge developed. The COD-load remains limited to about 4 kg of COD/m^3.day (27).

Sugarwork factories

The engineering consultancy Grontmij has developed an anaerobic treatment plant to treat the waste water from sugarwork factories. The waste water has a high content of starch and invert-sugars. The plant has already been started up. The load by volume is 9 kg of COD/m^3.day and the conversion is 90% (based on COD) (28).

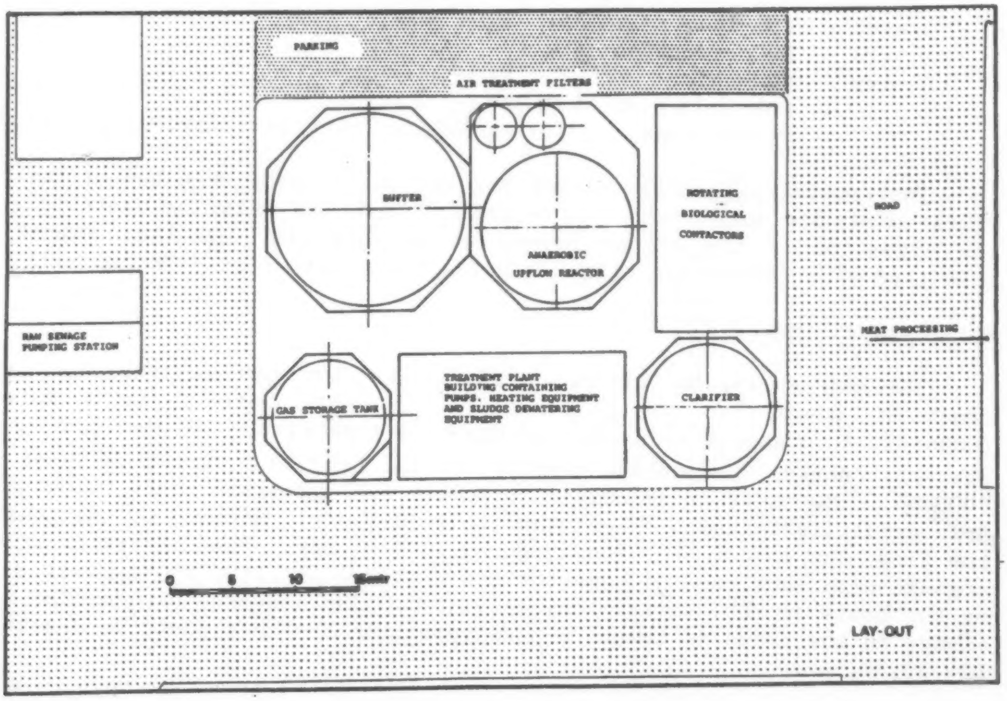
PARKING
AIR TREATMENT FILTERS
BUFFER
ANAEROBIC
UPFLOW REACTOR
ROTATING
BIOLOGICAL
CONTACTORS
ROAD
MEAT PROCESSING
RAW SEWAGE
PUMPING STATION
GAS STORAGE TANK
TREATMENT PLANT
BUILDING CONTAINING
PUMPS, HEATING EQUIPMENT
AND SLUDGE DEWATERING
EQUIPMENT
CLARIFIER
0
5
10
15mtr
LAY-OUT

Figure 2. Waste water purification of slaughter-house waste water.

Dairy industry

The production of dairy products results in large amounts of waste water. Normally the waste water is treated aerobically. In 1984 the Dutch consultancy Grontmij applied the so-called AB-process for the purification of dairy waste water. The AB-process consists of a high-loaded aerobic first step (A) with sludge recycling and a sedimentation tank. The second step (B) is a low-loaded aerobic one with sedimentation and separate sludge recycling.

There has been an investigation on a pilot-plant scale with a flow of 240 l/h. The waste water (dairy/cheese factory) had the following features:

-	COD	3000 mg/l
-	Kjeldahl-N	110 mg/l
-	pH	5.0-13.0
-	Temperature	24 °C
-	COD/BOD	1.6

The following results have been obtained:

-	A step	COD-load	35	kg/m^3.day
		BOD-reduction	45%	
-	B step	COD-load	1.7	kg/m^3.day
		BOD-reduction	97%	
		Sludge load	0.3	kg BOD/kg volatile suspended solids per day

The removal percentage of BOD for the whole plant were better than 99%. The waste water did not have to be neutralized. The settling characteristics and the digestion of the sludge proved to be excellent. At this moment the construction of a full-scale plant is being taken into consideration (29).

Maize starch industry

The engineering consultancy Heidemij has developed an anaerobic waste water treatment plant for the purification of waste water from a maize starch industry. It concerns a reactor of the UASB-type with a volume of 800 m^3. Before the water enters the methane reactor, it is held in a buffer basin of 1000 m^2. The basin is necessary to smooth the hydraulic peaks in the flow. Some acidification also takes place in this basin. Because of the peaks in the flow, the load varies from 5-30 kg (COD/m^3.day. The conversion of the organic materials remains nevertheless highly constant. The removal, on the basis of BOD, varies between 91-94%. The presence of granular sludge in the plant is taken to be responsible for this positive result (26,30,32,32).

Potato starch industry

The potato starch industry is a very important branch of industry in the Netherlands. The winning of starch from potatoes results in large amounts of waste water. For the purification of this water an anaerobic reactor of 5500 m^3 was built in De Krim. After 4 years the following results have been obtained:

- Sludge-activity	0.65 kg COD/kg volatile suspended solids.day
- biogas production	1000-1200 m^3/h
- COD conversion	16.5 kg COD/m^3.day
- COD reduction	80%. (31,33).

Yeast- and alcohol industry

Gist-Brocades of Delft is a yeast- and alcohol producing factory. With governmental financial support Gist-Brocades has developed an anaerobic fluidized bed plant.

In the beginning of 1984 the full scale reactors were started up. It concerns a two-phase process. The acidification-reactor has a volume of 80 m^3. The methane-reactor has a volume of 300 m^3.

The following results have been obtained:

- Acidification

COD-load	60 kg/m^3.day
COD-conversion	13 kg/m^3.day
Sludge activity	0.8 kg COD/kg. volatile suspended solids day
COD-reduction	about 20%

- Methanization

COD-load	47 kg/m^3.day
COD-conversion	30-35 kg/m^3.day
Sludge-activity	2-2.5 kg COD/kg volatile suspended solids day
COD-reduction	about 70%

The third step of the plant consists of a nitrogen removal reactor. In this reactor nitrification and sulfide-oxidation take place. The micro-organisms are also fixed to inert materials in this reactor. The laboratory- and pilot-plant experiments have already been completed. In the reactor a nitrogen-conversion of 1.5-2.0 kg Nitrate-N/m^3.day at a retention time of 1.5 hours is obtained. On account of the positive results a full-scale reactor with a volume of 300 m^3 will be built in 1986 (26,32,34).

Gist-Brocades has also put a full-scale plant into operation to regain ammonia from waste water. In this case it concerns waste water with a large amount of solvents. The purification method is based on cold extractive distillation (35).

Breweries

In 1984 the construction firm Paques BV carried out a pilot-plant investigation on anaerobic treatment of brewery-waste water. The waste water had a very low COD (1000-1500 mg/l) content and a low temperature (20-24 °C). Nevertheless, results were positive enough to merit the construction of a full-scale plant.

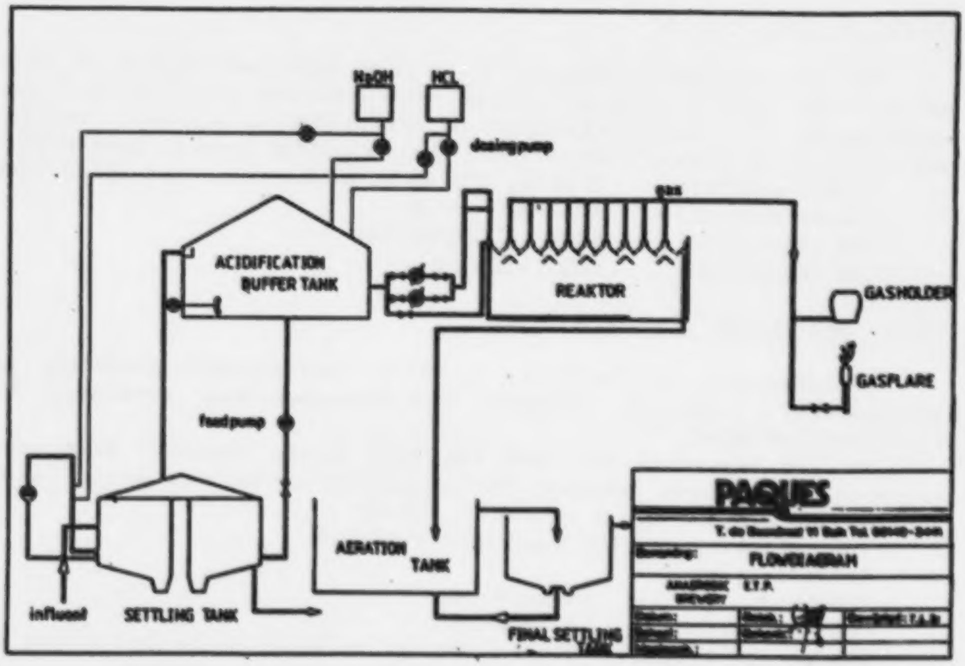
NaOH
HCL
dosingpump
gas
ACIDIFICATION BUFFER TANK
REAKTOR
GASHOLDER
GASFLARE
feedpump
PAQUES
FLOWDIAGRAM
E.T.P.
AERATION TANK
influent
SETTLING TANK
FINAL SETTLING TANK

Figure 3. Anaerobic treatment of brewery waste water.

The full-scale plant (see Figure 3), was put into operation in November 1984 and is characterized by the following features:

- Flow	6000 m^3/day
- COD-influent	1000-1500 mg/l
- Temperature	20-24 °C
- Volume buffer	1500 m^3
- Volume UASB-reactor	1400 m^3

. Because the plant was started up with sludge of another waste water treatment plant it reached design capacity within two weeks.

The results of the full scale plant are very similar to those of the pilot-plant:

- COD-load	4.5-7 kg COD/m^3.day
- COD-reduction	80%
- Biogas-production	0.25 m^3/kg COD (removed).

Because of the construction of the anaerobic plant the quality of the sludge of the aerobic plant (second step) of the waste water purification improved. The effluent quality is less than 5 mg BOD/l (36,37,38).

Paper industry

The waste water of paper factories contains among other things cellulose. Waste and waste water containing cellulose are very hard to treat, because cellulose is difficult to degrade.

The department of microbiology of the University of Nijmegen studies the destruction of high concentrations of cellulose containing wastes such as verge grass, and primary and secondary sewage sludge from waste water treatment plants applied in the paper- and cardboard-industry. The experiments are carried out by way of a two-phase-system consisting of a mixed reactor on laboratory scale (30 l) connected in series with a UASB-reactor.

In the first phase cellulose fibers are partly converted by micro-organisms by hydrolysis into fatty acids, carbonic acid and hydrogen. Methane is formed out of hydrogen and carbon dioxide. The aqueous phase with the dissolved fatty acids is pumped into the UASB-reactor where the acids are converted into methane.

On laboratory scale positive results have been obtained. Some results are presented in Table 7.

TABLE 7. RESULTS LABORATORY STUDY

Waste	Load (kg COD/m^3.day)	Retention-time (days)	COD-reduction (%)
Paperpulp	30-40	2	60-70
Grass	30-30	2	70-80
Potato-waste	20	2	60-70

Potential sources for application may be waste- and waste water streams from the paper industry, waste- and waste water streams from the canning industry, the processing of verge grass, wastes from parks, the processing of waste from vegetable markets etc.

The system will be further developed through the testing of a reactor on a pilot-plant scale at an industrial firm. This phase will be started in 1985 (39).

Large amounts of water are used in paper making. The waste water contains high concentrations of dissolved organic substances and must be treated via a biological process. In 1981 Bührmann-Tetterode, a Dutch paper industry group, started a study on the application of anaerobic waste water treatment.

After a short testing period on laboratory scale a pilot-plant was put into operation. The results were satisfactory enough that at this moment three full-scale plants (Figure 4) for paper industries have been realized in co-operation with Paques BV (Balk) and a fourth plant is currently under construction (Industrie-water Eerbeek).

By using anaerobic (pre)treatment, short pay-back times may be realized (about 1.5 years). Moreover, the present overloaded aerobic treatment plants will come down in costs after they have been expanded with an anaerobic pre-treatment system.

Table 8 gives a survey of the anaerobic treatment plants in the paper industry.

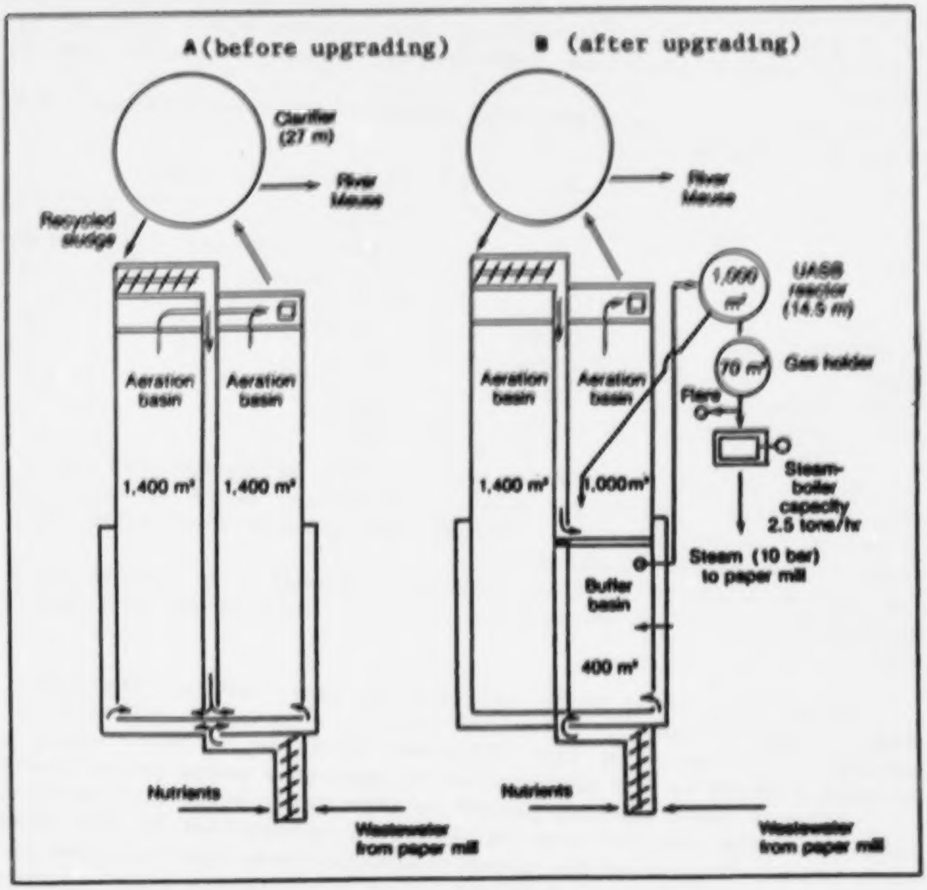
A (before upgrading)
B (after upgrading)
Clarifier (27 m)
River Meuse
Recycled sludge
Aeration basin
Aeration basin
1,400 m^3
1,400 m^3
Nutrients
Wastewater from paper mill
River Meuse
1,000 m^3
UASB reactor (14.5 m)
70 m^3
Gas holder
Flare
Steam-boiler capacity 2.5 tons/hr
Steam (10 bar) to paper mill
Aeration basin
Aeration basin
1,400 m^3
1,000 m^3
Buffer basin
400 m^3
Nutrients
Wastewater from paper mill

Figure 4. Schematic diagram of the waste water treatment plant at Papierfabriek Roermond.

TABLE 8. ANAEROBIC WASTE WATER TREATMENT PLANTS IN THE PAPER INDUSTRY (40) (SEPTEMBER 1985)

Factory	Product	Date of operation	Reactor volume (m^3)	Temp. (°C)	Load (kg COD/ m^3.day)	Infl. COD (g/m^3)	COD-reduction %
Ceres	Cardboard	April 1983	70	35	9	5000	70
Papier-fabriek Roermond	Testliner cora-medium Schrenz	October 1983	1000	30-40	10	3500	75
Celtona	Hygienic paper	November 1984	700	20-25	5	1200	60
Others	Testliner cora-medium cardboard envelopes	September 1985	2200	25	*	ca.1300	*

Fertilizer-industry

The production of phosphoric acid, a raw material for phosphate fertilizers, results in the formation of about two million tons of waste gypsum a year. Until now this gypsum has been discharged into surface water. Since gypsum from phosphoric acid production is contaminated with heavy metals, among which are cadmium and mercury, governmental policy has been directed at stopping these gypsum discharges. However, it has so far proved impossible to find suitable processing- or marketing potentials for phosphate-gypsum. Government, industry and research institutes, cooperating in the "Phosphate-gypsum working group", are making enquiries into the potential of phosphate-gypsum, by supporting research projects among other things.

The Dutch firms UKF, DSM and the Technological University of Delft are carrying out research on the development of a new phosphoric-acid process. This process distinguishes itself from the conventional hemihydrate processes by dividing the disclosure of the phosphate ore and the crystallization of the hemihydrate -which normally occur simultaneously - into two separate stages. In the first stage, the so-called predisclosure stage, the ore is totally converted into a monocalcium phosphate (MCP) solution by a recycle stream of phosphoric acid, whereupon hemihydrate is precipitated (Figure 5). Impurities such as heavy metals - present in the ore - are removed during, or directly after the predisclosure. This process makes it possible to produce a relatively clean gypsum and phosphoric acid. The study is still in a laboratory phase. At the end of 1986 the technical, economical and environmental consequences of this promising process will have become more clear (41).

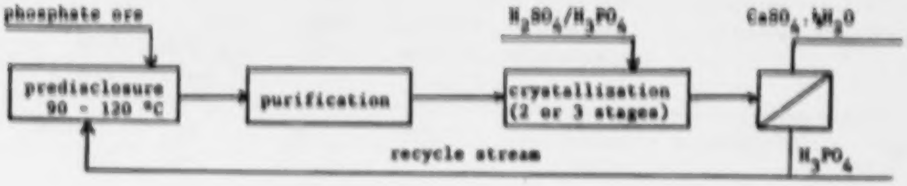

Figure 5. Process scheme of new phosphoric acid process.

Oil-containing waste water streams

The treatment of oil-containing waste water streams from garages, bunker-stations and waste-oil refiners can be improved using membrane filtration, flocculation/flotation or flocculation/filtration. The use of conventional oil-separators results into an oil concentration in the effluent of about 200 mg oil/l or more. By using the above mentioned techniques, concentrations of less than some scores of mg of oil/l may be reached. However, the average costs will increase by a factor 2 to 5.

These are the results of a study done by Tebodin Engineering Consultancy by order of the Governmental Institute for Waste Water Treatment.

Electrochemical detoxification of aqueous waste solutions

TNO has studied a method which uses cathodic dehalogenation of pentachlorophenol (PCP) in aqueous solution as a model reaction. PCP has been chosen because it is a representative pollutant of the type of waste waters in question, and because it has strong carbon-chlorine bonds and a relatively high solubility in (alkaline) aqueous solutions.

After 30 minutes of electrolysis the PCP concentration (Figure 6) had fallen below the detection limit of 0.5 ppm. Simultaneously, the chloride content of the solution showed that five chlorine atoms per molecule of PCP were removed. The current efficiency for complete dehalogenation is 1%. The adding of small quantities of certain surface active agents, improves the efficiency.

During electrolysis the toxicity of the solution fell from an initial EC 50 = 2% to a final 40%, indicating almost complete detoxification.

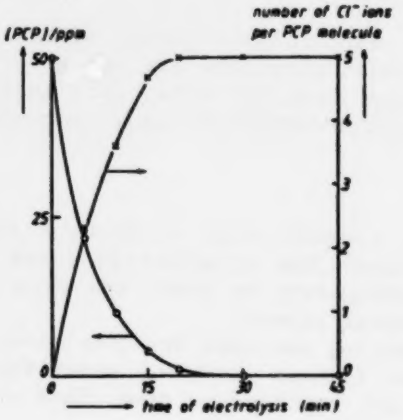

Figure 6. Decay of PCP and yield of Cl ions per PCP molecule during electrolysis of 1 litre of solution containing 50 ppm PCP.

An experiment with two litres of the test solution was conducted for the purpose of determining the intermediates and product(s) formed. Figure 7 shows the formation and decay of tetra-, tri-, di- and monochlorophenols, finally resulting in the formation of phenol and, possibly, monochlorophenols. The experiment shows that the total molar concentration of the phenols remains constant in time.

Experiments with other organohalogens and industrial waste waters are in progress.

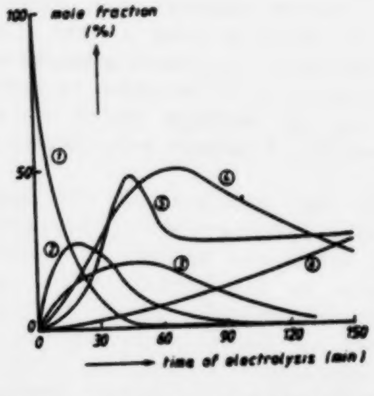

Figure 7. Mole fraction of the phenols during electrolysis of 2 liters of solution containing 50 ppm PCP.

1. PCP
2. tetrachlorophenols
3. Trichlorophenols
4. dichlorophenols
5. monochlorophenols
6. phenols

The advantage of electrolysis over alternative methods of chemical treatment is that additional chemicals are not generally required. Electrolysis with electrodes of a large specific area, such as those composed of very thin fibres, may reduce the concentration of toxic compounds to a very low level.

Agricultural industry

Seed-potatoes are treated with a mercury containing disinfectant for protection against diseases. The disinfection takes place in plunging tanks. In the Netherlands it is obligatory to treat the used mercury containing plunging liquids at specified central places.

In the past the treating was done decentralized, with activated carbon. The use of activated carbon filters rendered unsatisfactory results, because the saturated filters were not replaced in time. This resulted in soil- and surface water pollution.

In 1984 a central treatment plant was put into operation in Dronten. The treatment plant consists of the following process steps:
- Pre-sedimentation
- Coagulation/flocculation
- Sedimentation
- Filtration
- Activated carbon adsorption

The effluent figures are mostly below 10 µg/l mercury.

AGRICULTURAL WASTE WATER (MANURE PROCESSING)

Owing to the great increase and the concentration of the so-called bio-industry during the last decades in the Netherlands, a large surplus of manure (mainly pig- and cattle manure) has formed. Roughly estimated, this surplus amounts to about 17 million tons a year. This surplus constitutes a menace to the fertility of the soil (too much phosphate) and the environment. The emission of ammonia, the formation of nitrate in ground water, eutrophication of surface water and pollution of surface water by salts present in the manure may be mentioned. The problem of manure surplusses is mainly a problem of minerals.

In principle the problem of the manure surplusses may be solved. A possibility is the large-scale processing of manure surplusses in central processing plants where the manure is converted into products, which no longer constitute a menace to the fertility of the soil and the environment. Central processing of manure may take place in various ways. Each way consists of a series of a number of known processes or unit operations. The more important processes are: anaerobic digestion, separation, dewatering, NH_3-stripping, desalination, concentration, drying, combustion and aerobic biological treatment. In Figure 8 one of the potential ways of processing is outlined. Most of these unit-operations are frequently applied in the processing industry. The various ways of processing are distinguished by differences in endproducts and running costs. Dependent on the market for endproducts, a selection may be made for the best possible way of processing.

The costs for central manure processing are estimated at 30 to 60 Dutch guilders per m^3 of manure to be treated, for a plant capacity of some hundreds of thousands of m^3 a year, not including the costs for transportation of the manure to the central processing plant. The profit of potential products, which can be obtained at the central manure processing plant, are not taken into account. This expected profit, however, will not cover the total costs of manure processing.

On short-term, central manure processing might solve the problem of the manure surplusses. Perhaps long-term solutions are also possible by way of the cattle feed. The paramount thought is of a pre-treatment of the feed, aimed at the improvement of the nitrogen digestibility and the increase in the availability of phosphorus, or, of an alteration of the composition of the feed, aimed at a reduction in the nitrogen and phosphorus content and any other minerals such as, e.g. potassium.

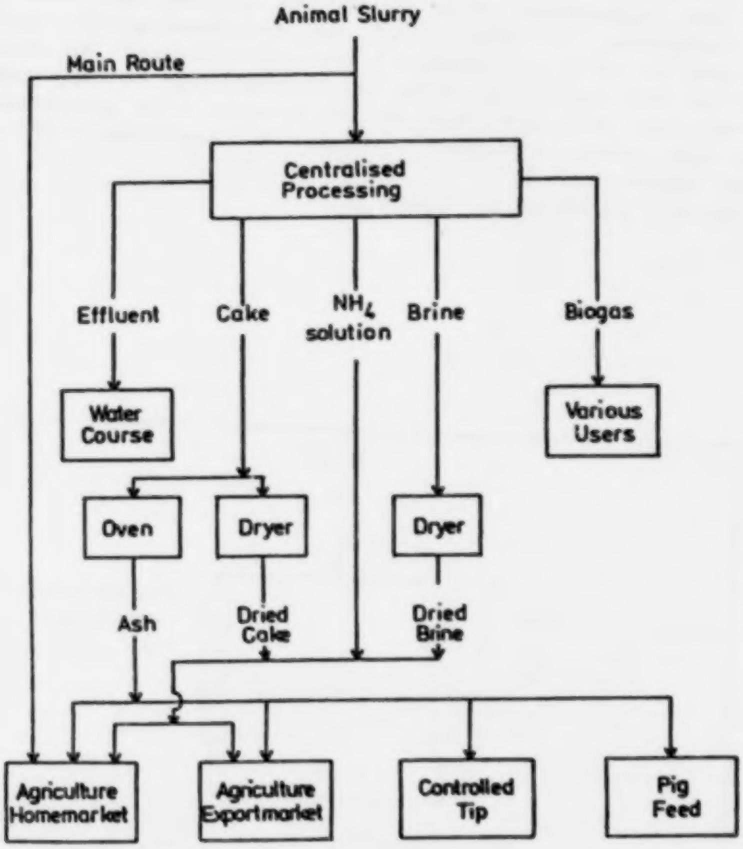
Animal Slurry
Main Route
Centralised Processing
Effluent
Cake
NH_4 solution
Brine
Biogas
Water Course
Various Users
Oven
Dryer
Dryer
Ash
Dried Cake
Dried Brine
Agriculture Homemarket
Agriculture Exportmarket
Controlled Tip
Pig Feed

Figure 8. Manure processing.

GROUNDWATER

Owing to the production of manure surplusses and connected over-manuring, at some locations the nitrate content in groundwater has greatly increased during the last years. A high concentration of nitrogen in ground water creates a problem for the preparation of drinking water. The problem has become even more pressing since on 1 July 1984 the standard for nitrate in drinking water was brought down from 100 mg/l to 50 mg/l.

Recently the Landbouwhogeschool Wageningen (Agricultural University) developed a method to remove nitrate from groundwater. The method consists of a combination of two techniques, namely, ion exchange and microbiological denitrification. Nitrate ions are adsorbed in the ion-exchanger. After saturation regeneration takes place, releasing the nitrate. The regenerate, high on nitrate content is then biologically denitrified, by which process nitrate is converted by micro organisms into elementary nitrogen under the addition of methanol. The regenerate, from which the nitrate has been removed, contains hydrogen carbonate, a product of the microbiological conversion. Hydrogen carbonate may be used to regenerate the ion-exchanger, so that the regeneration liquor may be used again. By using two ion-exchange columns and one denitrification column, one exchanger may adsorb nitrate from groundwater, while at the same time the other exchanger -which is saturated with nitrate - may be regenerated again.

The process is shown in Figure 9.

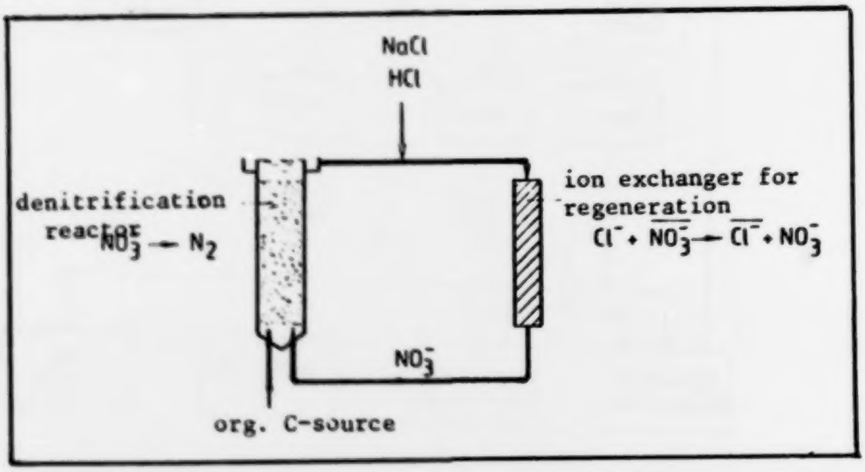
NaCl
HCl
denitrification reactor
$NO_3^- \rightarrow N_2$
ion exchanger for regeneration
$Cl^- + \overline{NO_3^-} \rightarrow \overline{Cl^-} + NO_3^-$
NO_3^-
org. C-source

Figure 9. Biological regeneration of an ion exchanger by means of a denitrification column.

The major benefits of this process are:

- The groundwater that is to be treated does not come into contact with the denitrifying organisms and the carbon source (e.g. methanol);
- The regeneration of the ion-exchangers takes place in a closed loop. A bulky waste brine, such as is the case in the usual way of regenerating, is therefore avoided. Regeneration of the ion-exchanger may of course also be carried out with chloride, e.g. as NaCl or HCl.

The chloride content in the recirculation loop must be maintained at a constant level, so that salt consumption for the regeneration will also decrease. Aspects, which will come forward in the investigation are:

- The adaptation of denitrifiers to a high chloride content;
- The prevention of a pollution of the ion-exchanger in the regeneration loop with organic material;
- The effect of an increasing sulphur content on the regeneration. Sulphur will accumulate in the regeneration loop, because it is fixed during the removal of nitrate and is released again during regeneration. However, contrary to nitrate, sulphate is not converted (42,43,44).

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NORWEGIAN ADVANCES IN WASTEWATER TREATMENT

by

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ABSTRACT

This paper gives a short summary of some recent advances in wastewater treatment and sludge handling in Norway.

Projects briefly summarized are:

- Aerobic, thermophilic digestion of pre-thickened sludge using air.
- Septage handling.
- Phosphorus removal from wastewater by the use of granular activated alumina.
- Treatment plants for single houses.
- Wastewater treatment with aerated submerged biological filters.
- Separate treatment of septage liquor.

INTRODUCTION

In Norway today research concerning industrial and municipal wastewater treatment and sludge treatment is mainly carried out by Aquateam, Norwegian Water Technology Centre A/S and by The Water Treatment Group, Norwegian Hydrotechnical Laboratory, The University of Trondheim.

This paper will give a short summary of some of the recent projects relevant to advanced wastewater treatment and sludge handling.

SLUDGE MANAGEMENT

AEROBIC THERMOPHILIC DIGESTION OF PRE-THICKENED SLUDGE USING AIR

Several methods for hygienization of sewage sludge have been evaluated in Norway: lime treatment, composting, long-term storage and aerobic, thermophilic digestion using pure oxygen. In 1983 the Danish company JANCA introduced on the Norwegian market a new version of the aerobic, thermophilic digestion process using a special device (vibrating sieve) for thickening the raw sludge up to 8-10% DS before digestion. With this concentrated sludge, a closed and insulated reactor and oxygen supply from a surface aerator, it was claimed that the sludge would be hygienized with a retention time of about 1 day (batch operation).

Aquateam has performed a pilot plant study of the JANCA-process at the HIAS sewage treatment plant (1). A flow diagram of the JANCA pilot plant is shown in Figure 1.

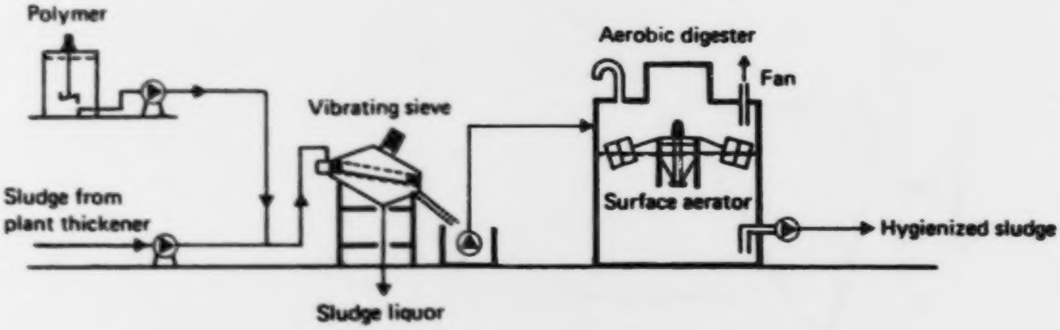


Figure 1. Flow diagram of the JANCA pilot plant.

The digester was operated on a draw and fill basis (batch operation). Mixed primary-activated-chemical (Al) sludge was pumped from one of the treatment plant thickeners to the vibrating sieve.

The hygienic quality of the sludge was monitored by microbiological examinations of faecal coliforms, faecal streptococci, spores of *Clostridium perfringens*, *Salmonella* bacteria and bacteriophages (coliphage MS 2). The bacteriophages were added to the feed sludge.

Due to variations in solids concentration of the pre-thickened sludge and operational problems with the thickening device, both organic and volumetric loadings on the digester varied considerable during the study. Table 1 gives data on retention time and organic loading for the test periods.

TABLE 1. LOADING DATA FOR THE DIGESTER

Phase	Retention time *) (days)		Organic loading (kg VS/m^3 . d)
	Range	Mean	Mean
Start-up	2.1-3.6	2.8	16
Test period 1	1.5-2.2	1.9	27
Test period 2	2.4-4.0	3.1	11

*) Retention time is calculated as the sludge volume in digester after feeding (m^3) divided by the sludge feed rate (m^3/d).

During test period 1 and 2 the digester temperature normally followed the curves shown in Figure 2.

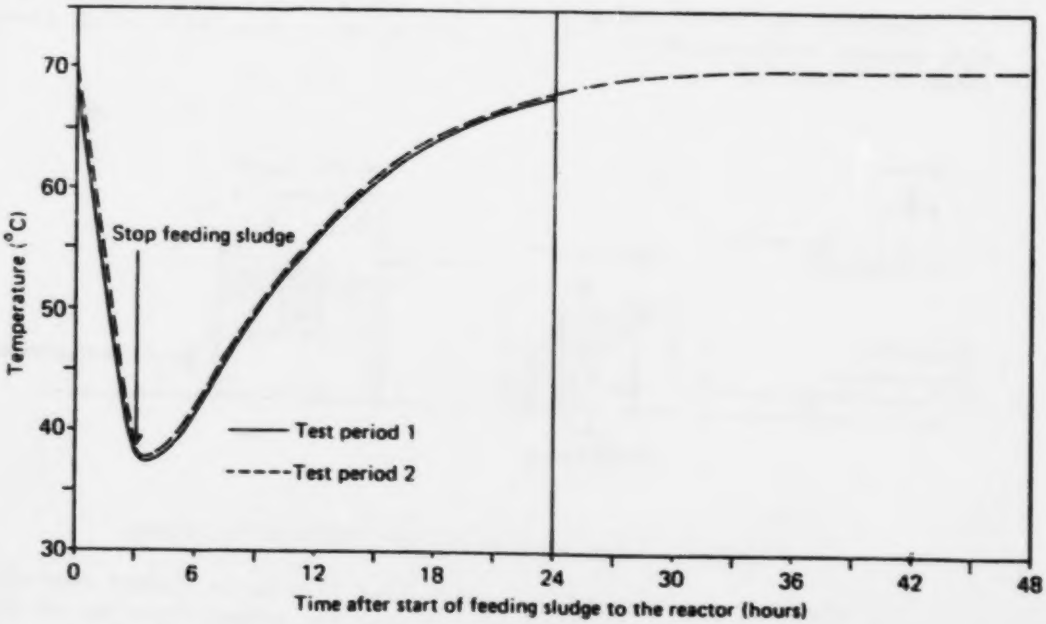


Figure 2. Typical temperature curves in digester after start of feeding sludge.

Based on the results from the pilot plant study the following conclusions were drawn:

- The JANCA-process with sludge draw and fill every morning (average retention time 1.9 days) could raise the sludge temperature to above 60°C and maintain this level for 8-12 hours. This caused a limited improvement in the sludge hygienic quality.
- With sludge draw and fill every second morning (average retention time 3.1 days) temperatures above 60°C could be maintained for 27-34 hours, and the sludge was satisfactorily hygienized.
- The data on organic matter reduction during the process is uncertain, but figures of 20-25% is indicated. This means the treated sludge is not stable and can create odor problems during subsequent handling and disposal.
- The original pre-thickening unit (vibrating sieve) did not function properly with the mixed primary-activated-chemical sludge. Mean dry solids concentrations after sieving was 7.1% and 5.5%, respectively, for test period 1 and 2. Another device (dewatering container) seemed to be capable of concentrating the sludge up to about 10% dry solids.
- Total power consumption for the pilot plant was 30 and 42 kWh per m^3 sludge from plant thickener with sludge feeding every day and every second day, respectively. These figures are higher than expected for a full scale plant with automatic process control.
- Capital cost for a 2100 tonnes DS/year plant is about NOK 2 million (1984). The operating costs (energy and polymer) will be about NOK 150/tonne DS.

SEPTAGE HANDLING

Treatment and handling of septage is a major problem in Norway. A project concerning separate treatment of septage liquor will be presented later in this paper. Here, a short summary of two other projects will be given.

Septage Discharge to Sewer System

The VEAS treatment plant outside Oslo is a primary precipitation plant designed to handle wastewater from 565,000 population equivalents. Septage from the Oslo area can be discharged to the sewer system.

During a test period Aquateam evaluated the effects of septage discharge on the operation and performance of the treatment plant and the sewer system (2). The sludge quantities used were the same as those expected to be discharged from the Oslo area in the future. The septage was added to the sewer about 25 km upstream from the treatment plant.

The results from the one month test period led to the following conclusions:

- It is possible to maintain the previous treatment efficiency at the treatment plant, even after addition of about 200 m^3/d of septage to the sewer system. This does, however, require a 10-15% increase in the consumption of chemicals (ferric chloride), in order to keep phosphorus concentration in plant effluent below 0.5 mg P/l. The sludge production will increase approximately 10%.
- The composition of the septage during the test period was such that installation of bar screens and a grit removal unit at the discharge facility was found unnecessary.
- Only a slight increase in odor level can be expected at the treatment plant. At some ventilation points along the sewer quite high odor levels were found. At these points the use of simple odor reduction methods should be considered.

Mobile Septage Dewatering

As an alternative to septage treatment at a wastewater treatment plant. mobile dewatering units have recently been introduced in Scandinavia. Mobile dewatering has several potential advantages:

- Reduced overall septage volume for treatment and ultimate disposal.
- Lower costs for transportation.
- Higher capacity. On-the-road dewatering increases the number of septic tanks that can be visited before disposal.
- Filtrate is returned to the septic tanks. This reduces the problems caused by adding untreated septage liquor directly to the treatment plant influent.

A Swedish system, called "Hamstern" was evaluated by NIVA (Norwegian Institute for Water Research) in 1980. This system is based on lime conditioning and dewatering in a special type of vacuum filter.

Recently Aquateam tested a Danish mobile dewatering system, called MOOS KSA (3). Figure 3 shows the sequential steps in septage collection and on-the-road dewatering using the MOOS KSA-system.

First the septage is sucked into a tank. Then filtrate from the previous dewatering is returned from the filtrate collection tank to the empty septic tank. Polymer is added when the septage is pumped from the vacuum tank to the dewatering tank. The sludge settles while the filtrate drains through a filter cloth to the filtrate collection tank. The dewatering sequence goes on all the time, while the truck goes from septic tank to septic tank. After a day of work the sludge is left in the dewatering tank overnight, in order to achieve higher dry solids concentrations.

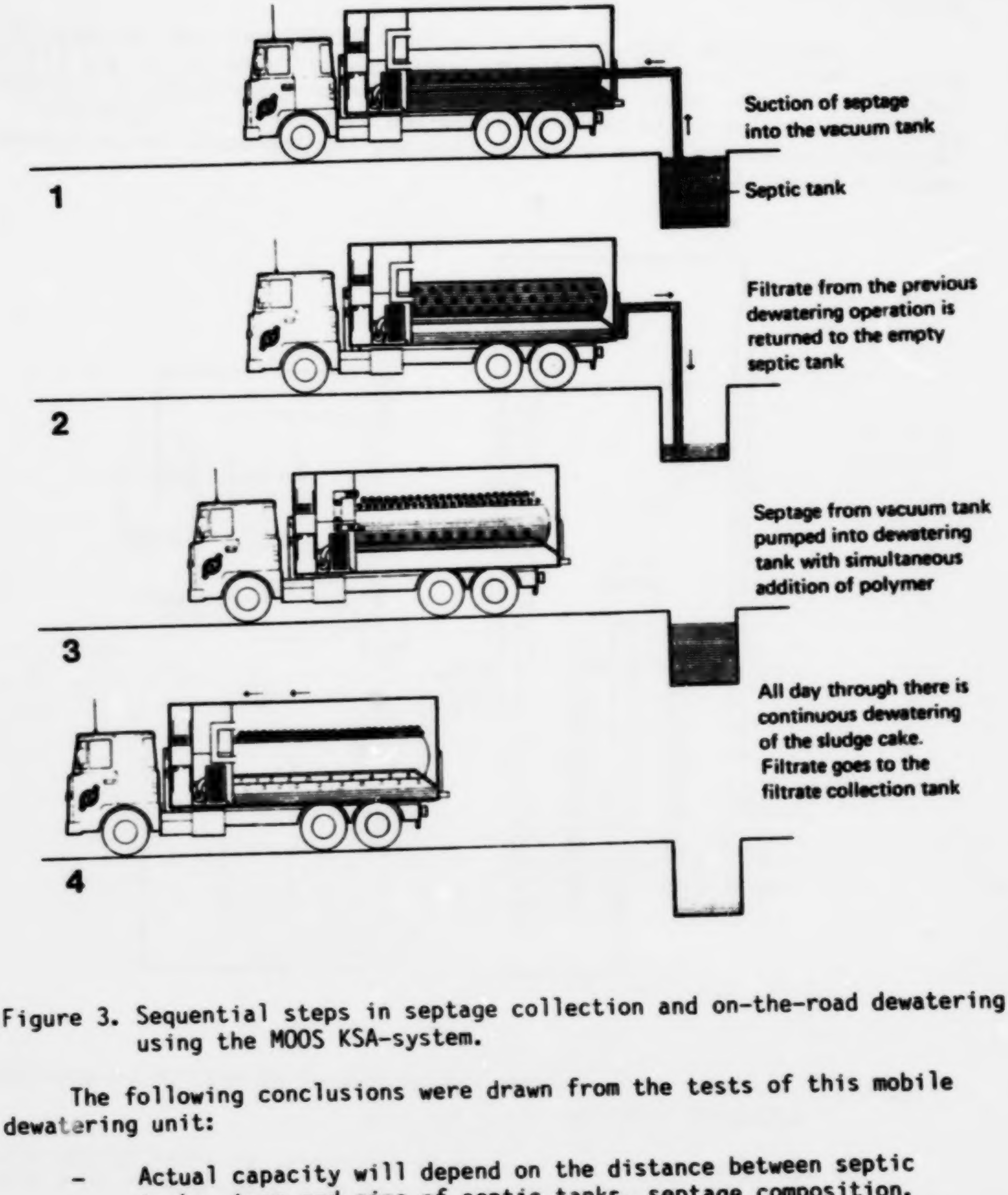

Suction of septage into the vacuum tank
Septic tank
1
Filtrate from the previous dewatering operation is returned to the empty septic tank
2
Septage from vacuum tank pumped into dewatering tank with simultaneous addition of polymer
3
All day through there is continuous dewatering of the sludge cake. Filtrate goes to the filtrate collection tank
4

Figure 3. Sequential steps in septage collection and on-the-road dewatering using the MOOS KSA-system.

The following conclusions were drawn from the tests of this mobile dewatering unit:

- Actual capacity will depend on the distance between septic tanks, type and size of septic tanks, septage composition, standard of roads, maximum allowable weight etc. Until we get performance in relation to the adsorption capacity and kinetics. Such an understanding is required in order to optimize the process design and operation. The scope of this work has been to contribute to such an understanding, in interpreting the results from isotherm and column experiments with the help of a mathematical model based on generally accepted mass transfer theory.

The Homogeneous Surface Diffusion Model (HSDM) was used to describe the process. More information about this model can be found in (4) and (5). The input data for the model was found in equilibrium experiments on alumina powder, and in lab-scale tests of fixed-bed adsorption of a synthetic secondary wastewater using granular alumina. The lab-scale column system is shown in Figure 4.

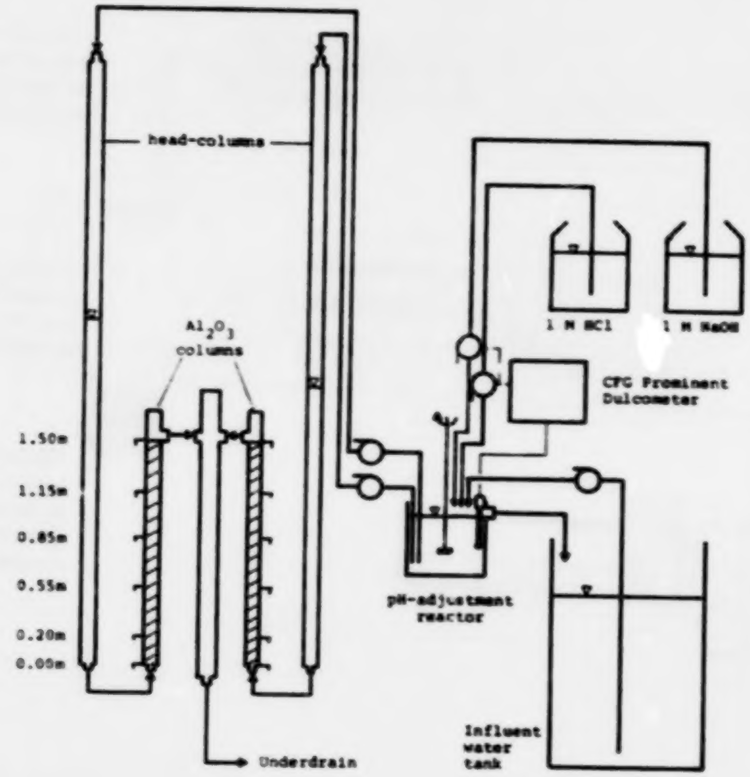
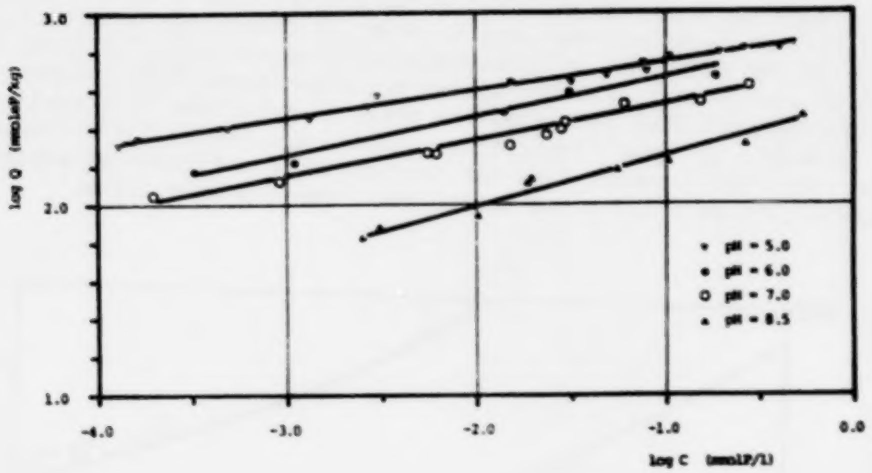

head-columns
Al_2O_3 columns
1.50m
1.15m
0.85m
0.55m
0.20m
0.00m
Underdrain
1 M HCl
1 M NaOH
CFG Prominent Dulcometer
pH-adjustment reactor
Influent water tank

Figure 4. Lab-scale column system for phosphorus adsorption on granular activated alumina.

The adsorption capacity is very pH-dependent, as shown by the adsorption isotherms in Figure 5. The capacity is at its maximum at pH = 4.5.



pH = 5.0 - K_F = 736.2 n = 0.127
pH = 6.0 - K_F = 714.5 n = 0.207
pH = 7.0 - K_F = 531.7 n = 0.208
pH = 8.5 - K_F = 317.1 n = 0.253

$Q = K_F \cdot C^n$, Q(mmoleP/kg Al_2O_3) C(mmoleP/l)

Figure 5. Adsorption isotherms for Compalox AN/V at different pH values, $T = 20^{\circ}C$, $t = 7$ days.

The HSDM model was found to give a fairly good description of the process. The process is well suited for designing a beds-in-series system. Figure 6 shows the recommended design criteria for a semi-continuous countercurrent system of three bed units with a total bed length of 6.0 m. The design criteria was calculated by the model for a pH of 6.0 and a required effluent quality of 0.5 mg P/l.

Figure 6 demonstrates that the influent phosphorus concentration and the alumina particle size are important factors regarding the design liquid flow velocity. A sensitivity analysis of the model stated that the three most important parameters determining the column performance were the pH, the alumina particle size, and the column length. The rate of adsorption is limited by intraparticle diffusion. Therefore the use of a coarse-grained type alumina will necessitate a low hydraulic loading and a long contact time within the bed.

Treatment of Real Wastewater

One possible application of this adsorption process is selective removal of phosphorus from small scale/on-site treatment plant effluents.

The effluent from a small RBC package plant was treated in two pilot-scale columns for a period of about 10 months (6). Coarse-grained type alumina (1.9 mm diameter) was used in order to reduce the potential for clogging of the beds. The influent concentration was close to 10 mg PO_4-P/1 and the pH was close to 7.0 throughout the experiment. Both columns had variable flowrates that simulated the daily fluctuations in a real treatment plant. However, the mean liquid flow velocity was low (0.2 m/h) in order to provide sufficient contact time for intraparticle diffusion of phosphate. The bed-heights were 1.0 m and the column diameters were 0.2 m.

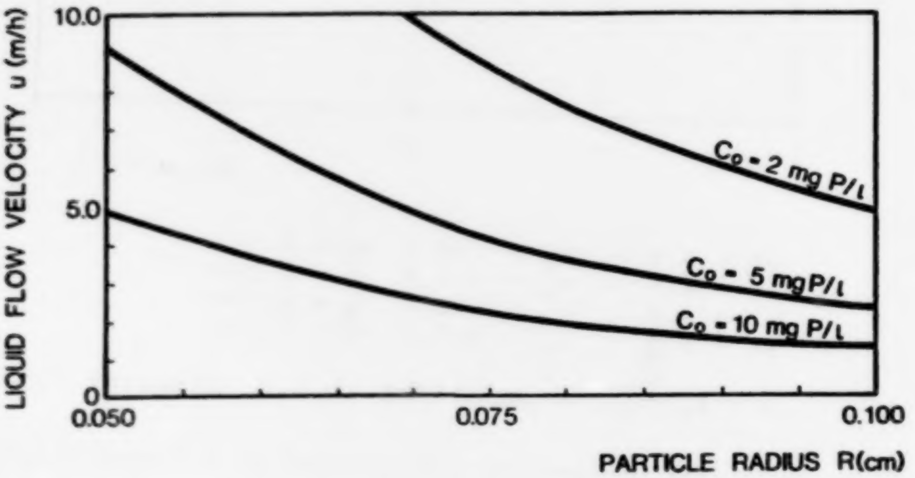


Figure 6. Recommended design criteria for a 6.0 m long in-series system of 3 bed units, for phosphorus adsorption on activated alumina (Compalox AN/V). Valid for pH = 6.0 and an effluent concentration of 0.5 mg P/1.

The breakthrough curves at different column lengths are shown in Figure 7. The dashed lines show the expected breakthrough curves for a simple phosphate adsorption process, as predicted by the mathematical model mentioned earlier.

From these results it is evident that a significant amount of phosphorus has been removed by mechanisms other than simple adsorption. Such mechanisms could be complexation, chemical precipitation by Ca^{2+} and Mg^{2+} present in the wastewater, and biological consumption of phosphate. Consequently, use of the mathematical model presented earlier on, will give conservative design criteria. It is, of course, an advantage that these mechanisms increase the column's capacity for phosphorus removal.

Phosphorus removal from wastewater using granular activated alumina seems to be an efficient and reliable treatment process, with a minimum of operation and maintenance requirements. However, important questions are still to be answered. The most urgent ones are pretreatment requirements and the influence of organic matter and more condensed type phosphates when treating a real wastewater, and in particular how regeneration of spent alumina should be optimized.

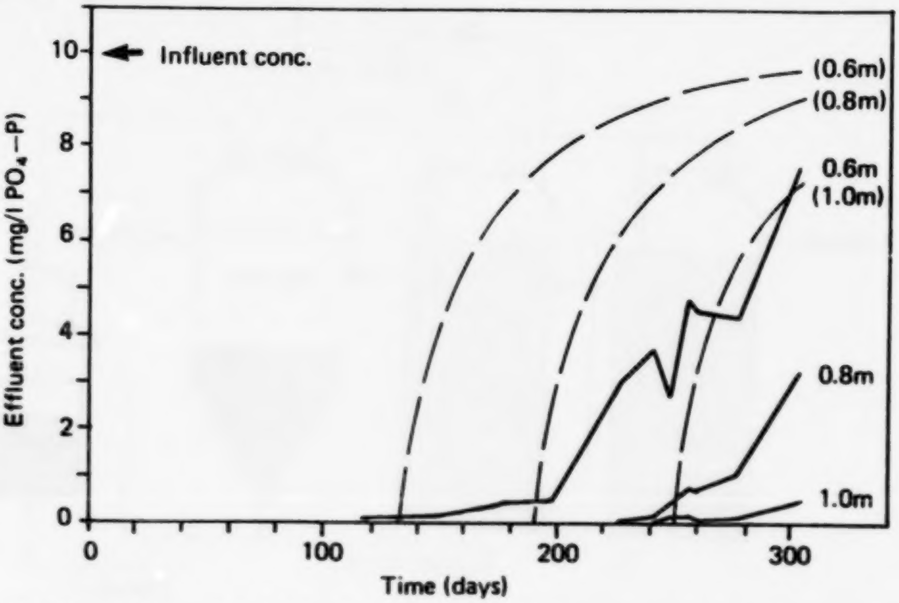


Figure 7. Breakthrough of PO_4-P at different column heights, treating real secondary wastewater. Columns filled with activated alumina (1.9 mm diameter Compalox AN/V). Solid lines show actual breakthrough curves, based on the mean value from the two columns. Dashed lines show expected breakthrough curves, predicted by a mathematical model.

TREATMENT PLANTS FOR SINGLE HOUSES

In a lot of countries there is a big demand for simple and reliable plants that can treat wastewater from a single house. These plants have to meet the regulatory effluent criteria under highly variable loads and over a long period of time.

Biovac A/S of Norway has developed and produces a unit for year-round treatment of wastewater from single houses. Over the last couple of years 10-15 such units has been monitored. Three units for removal of organic matter were closely monitored and evaluated over a 6-month period (7). Later two more units designed for removal of both organic matter and phosphorus were thoroughly tested by Aquateam from July 1984 to January 1985 (8).

Flow diagram of a BIOVAC treatment plant with co-precipitation of phosphorus is shown in Figure 8. In the two process tanks the wastewater is biologically treated in an aerated suspended growth system. A vacuum fan sucks air into the process tanks, keeps the sludge in suspension and recycles the sludge from the clarifier. The sludge return is intermittent and is controlled by a timer. Once a week, at night, the clarifier is stirred for a few seconds, in order to prevent accumulation of floating sludge.

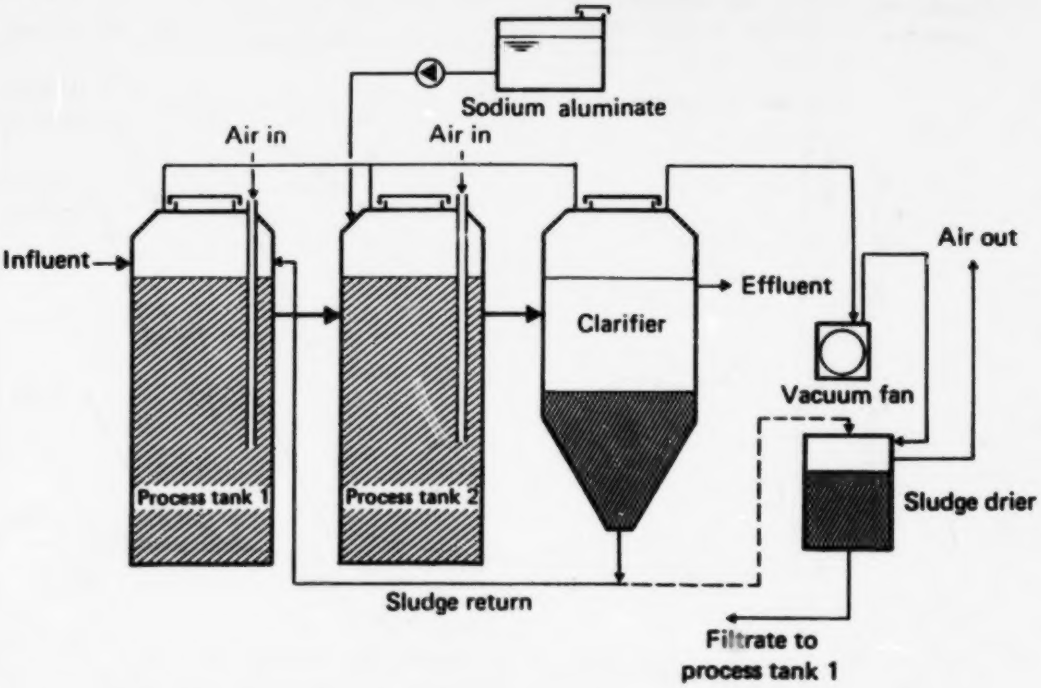

Sodium aluminate
Air in
Air in
Influent
Air out
Effluent
Clarifier
Vacuum fan
Process tank 1
Process tank 2
Sludge drier
Sludge return
Filtrate to process tank 1

Figure 8. Flow diagram of a BIOVAC treatment plant.

The process tanks have a total effective volume of 1.08 m^3, while the clarifier has an effective area of 0.35 m^2.

Liquid sodium aluminate ($Na_2Al_2O_4$) is used as precipitant. It is added to process tank 2 intermittently, either once every hour or once a day.

Excess sludge is pumped to the sludge drier by an airlift pump once a day. The sludge liquor is returned to process tank 1. The biological-chemical sludge dewaters quite well, and excess heat from the vacuum fan is used to dry the sludge further.

The plants are supposed to be routinely serviced every 4 months. The service people then dispose of the accumulated sludge and fill the sodium aluminate tank.

So far the BIOVAC treatment plants have been very reliable and have performed very well.

Oxygen concentrations between 2.5 and 6.3 mg/l have been observed in process tank 1, while the concentrations in process tank 2 have been slightly higher, 4.5 to 6.8 mg/l.

The organic loading has been low, with F/M-ratios from 0.02 to 0.07 kg BOD_7/kg MLSS . d. Hence, BOD-removal has been excellent, with effluent concentrations ≤ 10 mg BOD_7/l.

Co-precipitation with sodium aluminate has given residual total phosphorus concentrations of 0.1-0.6 mg P/l. An addition of chemicals equivalent to 2.0 mol Al/mol P is recommended. For a home with 4 people this will be equivalent to 11.7 l of sodium aluminate solution over a 4-month period.

Daily fluctuations in wastewater flow has no negative influence on the performance, provided that the total daily flow is less than 700 l/day.

WASTEWATER TREATMENT WITH AERATED SUBMERGED BIOLOGICAL FILTERS

Almost all the wastewater treatment plants in Norway are inside buildings. This is because of the strict rules governing working conditions and the cold winter climate. To reduce the plant construction costs, it is essential to use a compact treatment process. Many biodisc plants have been built in Norway during the last few years. They have, however, had some mechanical problems. An aerated submerged biofilter has no moving parts, and with a high density filter medium it should be possible to get a high organic removal rate per unit volume.

Figure 9 shows the principle for a two-stage aerated submerged biofilter.

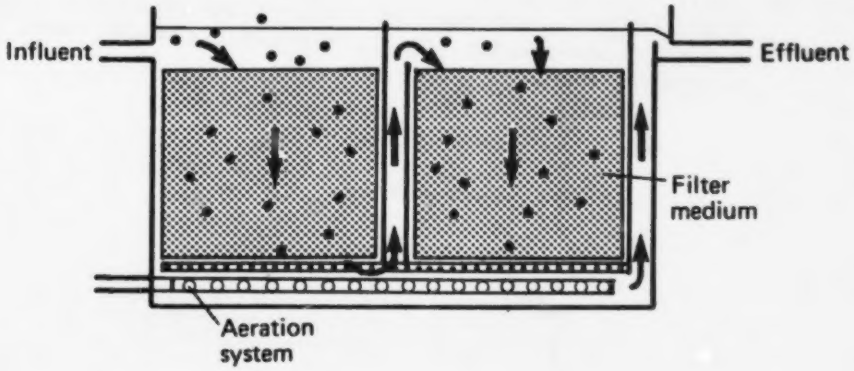


Figure 9. Principle lay-out of a two-stage aerated submerged biofilter.

In 1982 the Water Treatment Group at The University of Trondheim started pilot-scale research on aerated submerged biofilters. Filter media with specific surfaces of 140 m^2/m^3 and 230 m^2/m^3, respectively, were used to treat municipal wastewater (9). The removal rates were the same in both filters, as organic matter removed per unit surface area. Thus, the filter with the 230 m^2/m^3 medium gave the highest volumetric removal rate. The air bubbles stripped off excess biofilm and the strong turbulence also ensured that the substrate was evenly distributed to all parts of the filter. Tracer response curves showed both filters to behave as complete mix reactors.

Figure 10 shows removal rate versus organic load when the filters were run as single-stage reactors. Figure 11 shows the same with the filters operating as a two-stage reactor.

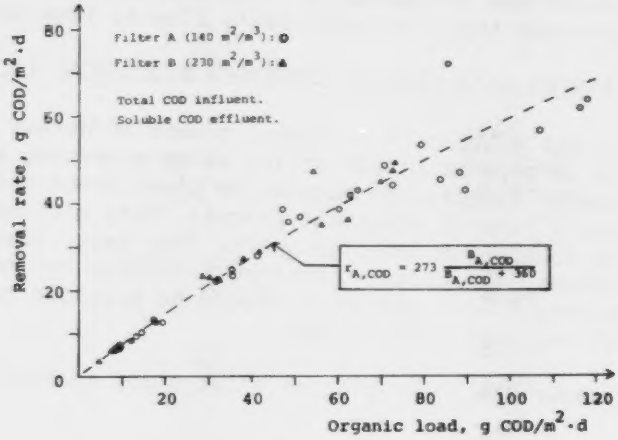


Figure 10. Total organic removal rate versus total organic load. Filter A and Filter B operated as single-stage reactors, treating municipal wastewater. $r_{A,COD}$ = organic removal rate, $B_{A,COD}$ = organic load.

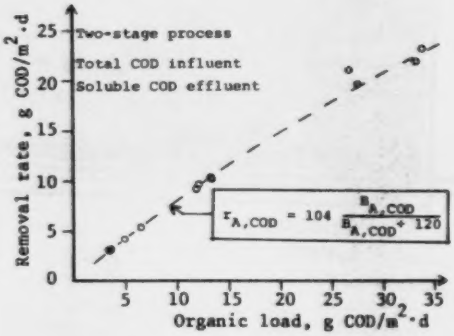


Figure 11. Total organic removal rate versus total organic load. Filter A and Filter B operated as a two-stage reactor without intermediate clarification, treating municipal wastewater. $r_{A,COD}$ = organic removal rate, $B_{A,COD}$ = organic load.

Volumetric removal rates in excess of 10 kg $COD/m^3 \cdot d$ were observed in both filters, treating municipal wastewater with low COD-concentration.

With the filters operating as single-stage reactors, specific sludge production was between 0.35 and 0.55 g TS/g COD removed. With the two-stage process the sludge production increased from virtually zero at an organic removal rate of 3 g COD/m^2 . d, up to 0.40 g TS/g COD removed at a rate of 25 g COD/m^2 . d.

Oxygen transfer was good in both filters. In a full-scale plant, with a depth of aeration of 3 m, an air supply of about 10 to 15 m^3 per kg COD applied should be sufficient with the tested filter media.

A different study compared high-rate treatment of food-industry effluents in an activated sludge unit and in a submerged aerated biological filter (10). The filter had a medium with a specific surface area of 230 m^2/m^3.

Removal rate versus organic load is shown in Figure 12, for the submerged biofilter. The maximum volumetric removal rate was in excess of 15 kg COD/m^3 . d. This was about four times higher than the maximum achievable rate in the activated sludge unit.

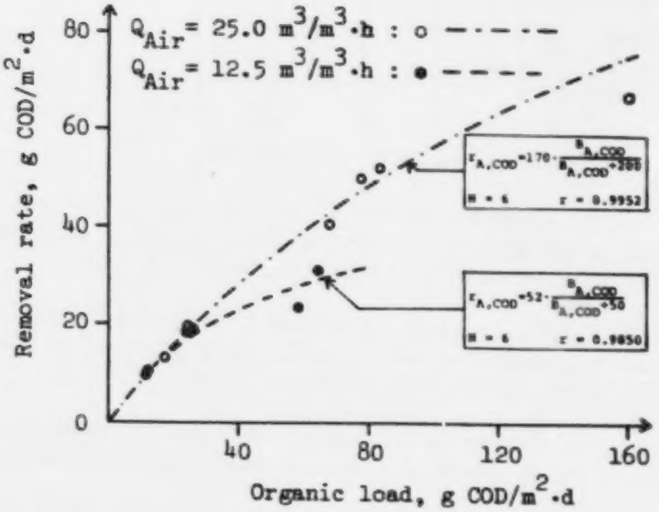


Figure 12. Total organic load versus total organic removal rate in the aerated submerged biological filter treating food-industry wastewater. Air supplies of 12.5 and 25.0 m^3 per m^3 filter volume and hour have been used. $r_{A,COD}$ = organic removal rate, $B_{A,COD}$ = organic load.

On an average basis, an effluent concentration of 1000 mg COD/l corresponds to a removal efficiency of about 70% using the wastewater in this study. The activated sludge unit and the biofilter could be loaded at 2.8 kg COD/m^3 . d and 12.7 kg COD/m^3 . d, respectively, in order to obtain an effluent concentration of 1000 mg/l. This shows that the aerated submerged biological filter was superior to the activated sludge process in terms of required tank volumes.

It can be seen from Figure 13 that the aerated submerged biological filter can be operated at a lower specific air supply than the activated sludge unit. With the same specific air supplies, the biological filter always showed the highest dissolved oxygen concentrations. The filter medium increases the contact time between the air and the liquid. Thus more oxygen can be transferred.

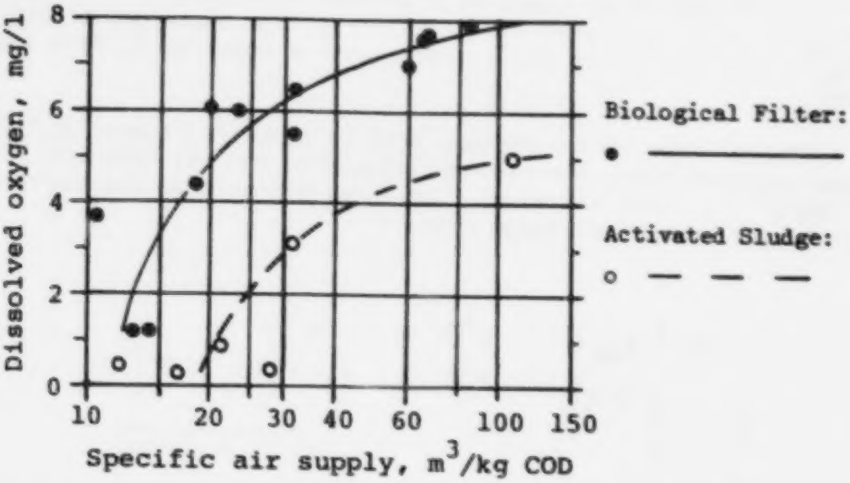


Figure 13. Specific air supply versus dissolved oxygen concentration for the two pilot-plants, treating food-industry wastewater. Data recalculated to a submerged depth of 3 m.

The first full-scale aerated submerged biological filter in Norway was put into operation in 1984. Two more plants were started in the spring of 1985 and several plants are on the planning stage.

Two of the plants in operation treat municipal wastewater. The third plant treats mainly dairy wastes, and some municipal wastewater.

As of yet there are no performance data available from these full-scale installations. However, aerated submerged biological filters seem to be a good alternative to other biological treatment processes. The microorganisms grow on the media, eliminating sludge recycle and any disturbance resulting from sludge bulking. Trickling filters need a certain minimum hydraulic load to work efficiently. In aerated submerged biological filters the air bubbles are believed to erode the biofilm and prevent clogging of the filter media. The strong turbulence also ensures good contact between substrate and microorganisms. An aerated submerged biological filter with a high surface area filter media should be a simple and compact treatment process.

SEPARATE TREATMENT OF SEPTAGE LIQUOR

Treatment of septage is a major problem in many European countries. In Scandinavia septage is quite often discharged directly to the sludge treatment units at a municipal sewage treatment plant. Small primary or secondary chemical precipitation plants are very common in Norway. The operational problems due to septage discharge have been severe at these plants. In addition, the return of untreated septage liquor to the treatment plant influent frequently leads to unacceptable effluent qualities.

One way to reduce the problems caused by septage discharge is to treat the septage liquor separately in a biological unit. No data about separate treatment of septage liquor have been found in the literature, except for a brief experiment made by the Norwegian Institute for Water Research.

In order to gain more knowledge, pilot-scale research using both the RBC-process and the activated sludge process was initiated in 1983. This led to a full scale demonstration project in 1984 and 1985. These projects were carried out by research engineers presently employed by Aquateam.

Pilot-Scale Research

This work had two main objectives: to study biological treatment of septage liquor, and to study chemical precipitation of treated and untreated septage liquor when mixed with primary treated municipal wastewater.

Treatment in RBCs (11)--

Biological treatment of septage filtrate was studied in two pilot-scale RBCs, one operating at 5.4°C and the other at 14.5°C. In addition, chemical precipitation of untreated and RBC-treated septage liquor, mixed with municipal sewage, was studied in order to find the effects of return flows of septage liquor on alum treatment of wastewater. The septage filtrate used in this study was less concentrated than typical septage liquor.

Figure 14 shows total organic removal rates versus total organic loads for the two RBCs. Most of the reduction of organic matter in the RBC systems took place in the first stage. Removal rates as high as 80-90 g $COD_T/m^2 \cdot d$ were observed at 14.5°C. A maximum removal efficiency of about 85% total COD was found at a temperature of 14.5°C and an organic load of about 80 g COD_T/m^2d.

Based on the removal rates of total COD at 5.4 °C and 14.5 °C respectively, a temperature coefficient (θ) of 1.10-1.11 was found.

The results indicated simultaneous nitrification and denitrification in the RBC unit operated at 14.5°C. The low temperature RBC unit showed no sign of nitrification.

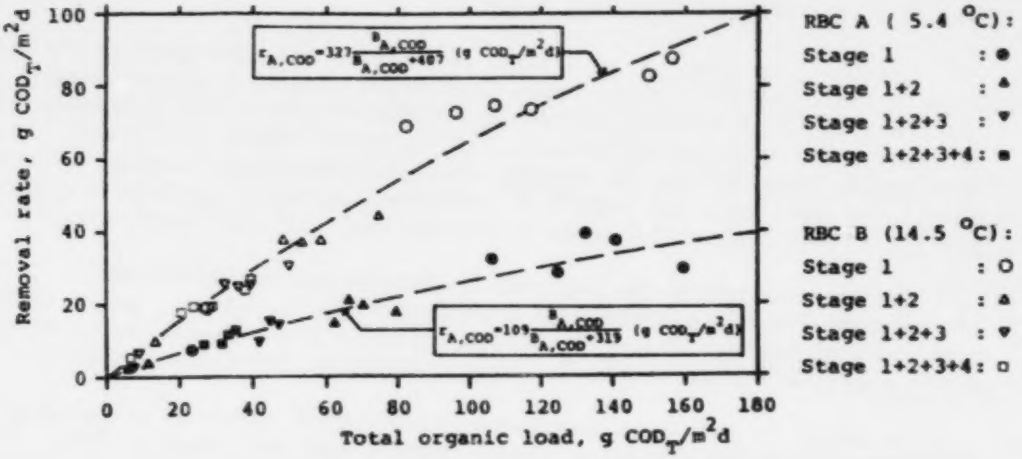


Figure 14. Separate treatment of septage filtrate in pilot-scale RBCs. Shows total organic removal rates versus total organic loads, based on data from all 4 stages. $r_{A,COD}$ = organic removal rate, $B_{A,COD}$ = organic load.

Jar-tests showed that nitrification of the septage liquor was required to reduce the consumption of chemicals for phosphorus removal.

Low effluent phosphorus and SS concentrations could be obtained in the jar-tests with both treated and untreated septage liquor. With respect to COD, previous RBC treatment was essential, as shown in Figure 15. High rate treatment in a RBC unit (<30% removal of COD_T) was sufficient to have a very positive effect on the residual concentrations of total and filtrable COD after blending with municipal sewage and precipitation with alum.

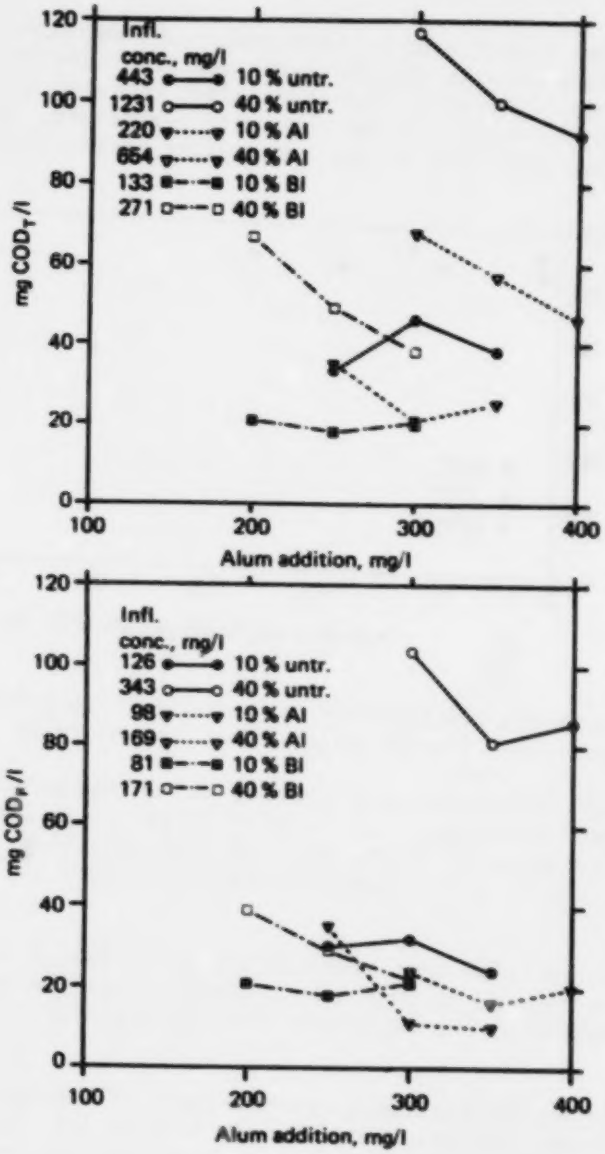


Figure 15. Total and filtrable COD concentrations after alum precipitation in jar-tests, for different fractions of RBC treated and untreated septic sludge filtrate in primary treated municipal wastewater.

Treatment With the Activated Sludge Process (12)—

The septage liquor used in this experiment was more concentrated than the filtrate used in the RBC-experiments. Figure 16 shows removal efficiency versus F/M-ratio. The pilot-plant operated at 8°C and a F/M-ratio of 0.41 kg BOD_7/kg MLVSS . d was obviously overloaded. Otherwise the pilot-plants performed excellent at the temperature levels indicated in Figure 16.

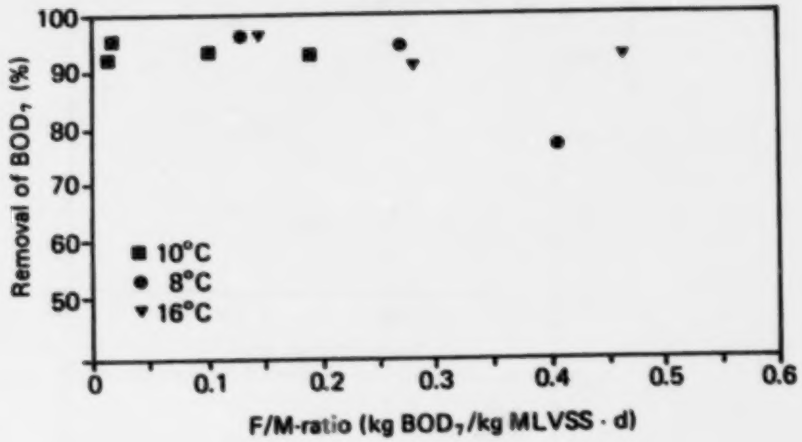


Figure 16. Separate treatment of septage liquor in pilot-scale activated sludge units. Shows removal rates versus F/M-ratios.

Chemical precipitation of treated and untreated septage liquor, mixed with municipal wastewater, was studied in jar-tests. The alkalinity of the septage liquor determined the required alum addition. Thus nitrification of the septage liquor is necessary in order to reduce the consumption of chemicals.

An alum addition equivalent to 2-3 mol Al/mol P is required for satisfactory removal of phosphorus. Consequently the phosphorus concentration will determine the necessary alum addition for nitrified septage liquor.

Similar to RBC-treatment, pretreatment of septage liquor with the activated sludge process significantly reduced the residual concentrations of organic matter after blending with municipal wastewater and precipitation with alum.

Full-Scale Demonstration Project (13)

Sørumsand sewage treatment plant was chosen for the full-scale demonstration project. This is a secondary precipitation plant designed for 6 000 p.e., but with an actual load of about 1 500 p.e. Alum is used as precipitant.

Septic sludge is discharged to the sewer a few yards upstream the treatment plant. The volume of septage discharged at this plant is equivalent to 5-10% of the total flow to the plant.

The sludge going from the plant thickener to the dewatering centrifuge is a mixture of septic-primary-chemical sludge. This is a common situation at many Norwegian treatment plants.

The full-scale test was carried out over a period of 6 months. The sludge liquor from the centrifuge was treated in an activated sludge unit, operated as a batch system.

Figure 17 shows the flow diagram for this process. Sludge liquor from the centrifuge flowed to a tank. From there it could either be returned to the treatment plant influent, or be pumped to the activated sludge unit. The activated sludge unit had a total volume of 30 m^3. Every morning a maximum of 17.5 m^3 of treated sludge liquor was pumped out of the tank, and replaced with an equivalent volume of untreated septage liquor. Air was supplied through coarse bubble aerators at the bottom of the tank.

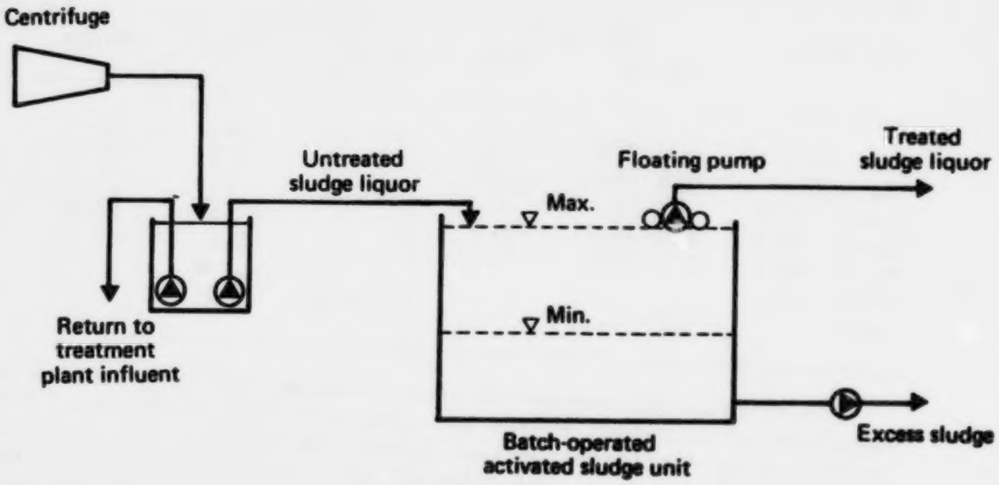

Centrifuge
Untreated sludge liquor
Floating pump
Treated sludge liquor
Max.
Min.
Return to treatment plant influent
Batch-operated activated sludge unit
Excess sludge

Figure 17. Flow diagram of a full-scale, batch-operated, activated sludge system for separate treatment of sludge liquor.

Dewatering units at Norwegian treatment plants are normally in operation only during regular working hours, from Monday to Friday. Thus, we had an ideal situation for batch operation of the activated sludge unit. A regular cycle was like this:

- Aeration was stopped early in the morning, and the sludge was allowed to settle for 1-1.5 hours.
- Treated sludge liquor was pumped to the treatment plant influent.
- Aeration was resumed and the tank was filled with untreated sludge liquor.
- Aeration was continued until the following morning.

On Saturdays and Sundays the activated sludge unit was aerated all day. The process cycle was controlled by two simple timers.

Results from a one month period with intensive monitoring are shown in Table 2. During this period the aeration tank had a pH of 6.8-7.2 and a temperature of 12-13 °C. The organic loading (F/M-ratio) was between 0.049 and 0.137 kg BOD_7/kg MLSS . d, with a mean value of 0.094 kg BOD_7/kg MLSS.d. A COD/BOD_7-ratio of 1.8 was found for untreated sludge liquor. Treated sludge liquor was not analysed for BOD.

TABLE 2. SEPARATE TREATMENT OF SLUDGE LIQUOR IN A FULL-SCALE PLANT. RESULTS FROM PERIOD WITH INTENSIVE MONITORING

Parameter	Influent		Effluent		Rem. Eff. %	
	Range	Mean	Range	Mean	Range	Mean
COD, mg/l	990-3050	1539	62-760	244	63-96	86
SS, mg/l	688-1403	1047	110-640	319	46-88	70
Tot-N, mg/l	68-237	110	20-111	60	1-73	45
Tot-P, mg/l	6.0-22.9	16.5	0.1-10.9	3.4	17-99	76
PO_4-P, mg/l	1.1-2.4	1.8	0.1-1.0	0.4	29-95	78
Alkalinity, meq/l	2.8-17.2	4.7	1.0-8.0	3.1	-	33

In general the removal of organic matter was very good. A fairly good reduction of suspended solids was also obtained. At the low F/M-ratios used in this study nitrification took place. The data are not consistent, but it is assumed that some of the nitrogen was used for cell synthesis, and that some was removed by nitrification/denitrification due to the batch operation of the activated sludge process.

The previous pilot-scale experiments have shown that the alkalinity and the phosphorus concentration determines the required chemical addition for phosphorus removal. Table 2 shows that the alkalinity was reduced, but only with 33% on an average basis. However, the removal of phosphorus was excellent. The removal of particulate phosphorus can be attributed to the reduction in suspended solids. The extremely low concentration of soluble phosphorus may have been caused by precipitation, due to the fraction of chemical sludge in the sludge mixture.

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RESEARCH AND DEVELOPMENT IN DOMESTIC WASTE WATER TREATMENT IN THE UK, 1985

by

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North Atlantic Treaty Organization/Committee on the
Challenges of Modern Society (NATO/CCMS) Conference
on Sewage Treatment Technology

October 15-16, 1985
Cincinnati, Ohio

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ABSTRACT

Research in the UK Water Research Centre in wastewater treatment include studies on sewage treatment, biological sludge treatment and handling, operational aids and management aids. Research in sewage treatment features studies on optimising aeration efficiency, both fine-bubble and mechanical surface aeration, energy saving in sewage pumping, the CAPTOR process, nitrification in a biological fluidised bed, anaerobic treatment of sewage, a modified rotating biological contactor system, and biological filtration of finely screened sewage. Highlights of the research in biological sludge treatment and handling include studies of aerobic digestion of sludge, submerged combustion of digester gas for prepasteurization of sludge, digester gas utilisation, consolidation thickening filter pressing control, oil from sludge and instrumental analyses of biogas. In operational aids, the research includes studies on desludging of sedimentation tanks, management of small dispersed unmanned plants and maintenance simulation studies. The research in management aids include studies on per capita sewage load assessment, cost performance indices and field evaluation of instruments.

1. INTRODUCTION

This paper provides a summary of the current state of R & D Projects being undertaken at the UK's Water Research Centre Processes Laboratory in Stevenage together with an overview of relevant research in British Universities.

1. Brief introduction
2. Sewage treatment
3. Biological sludge treatment and handling
4. Operational aids
5. Management aids
6. Research in British Universities (Appendix)

2. SEWAGE TREATMENT

2.1 OPTIMISATION OF FINE-BUBBLE AERATION

Since the last NATO/CCMS meeting this project has been completed. The object of the project was to improve the efficiency of oxygen utilisation in conventional fine-bubble diffused aeration sewage treatment plant (STP) and to achieve nitrification of the treated waste. The project was funded by the Water Research Centre, the UK Department of Energy, the US EPA and the Canadian Department of the Environment with assistance from the Thames Water Authority. The work was carried out on the Thames Water Authority's full-scale STP at Rye Meads.

Aeration tanks have been modified by the installation of an optimised diffuser layout and DO control system to achieve and maintain a 50% improvement in aeration efficiency compared to similar unmodified tanks.

Results have indicated that the production of a high quality, fully nitrified effluent may be no more expensive than the production of non-nitrified effluents if the costs of surplus sludge disposal are taken into account. The optimisation of the aeration tank layout and the installation of a DO control system also allows a greater flow rate of sewage per unit tank volume to be treated, thereby reducing the capital cost of new plants.

A general procedure for the design of efficient activated sludge plants has been established and published as a replication guide. Optimisation projects are currently in progress at about fifteen large activated sludge plants in the UK.

A cost-benefit study has been carried out by the Thames Water Authority on the "Net Present Value" of the energy which can be saved by introducing this system into all fine-bubble sewage treatment plants of >10,000 population: the NPV (using a discount rate of 5% and plant life of 20 years) was £16 million (about $22.5 million) (and roughly £35 million or $50 million for the UK).

The success of this project has led to the establishment of another project, the Optimisation of Mechanical Aeration (see below).

2.2 OPTIMISATION OF MECHANICAL SURFACE AERATION

A survey of the aeration efficiencies achieved at large activated sludge plants in the UK have revealed that diffused-air systems are potentially more efficient than surface aeration systems when installed in processes designed to produce fully nitrified effluents. However, it has been found that mechanical surface aeration systems may be more efficient in non-nitrifying processes.

The same general principles of optimisation of aeration efficiency should apply to surface aeration systems as well as diffused-air systems and there is potential for considerable energy savings to be made at large installations.

Accordingly a full-scale project has recently been initiated at the Blackburn Meadows STP of the Yorkshire Water Authority to develop improvements in surface aeration efficiency. One of the primary objectives of the project is to assess the performance of several different dissolved oxygen control mechanisms which may be used separately or in combination to vary the oxygenation capacity of surface aerators. These mechanisms include on-off switching of individual aerators, controlling aerator speed and adjusting the depth of immersion of aerators in the aeration tank (1).

Equipment for this project is being ordered this month and the project itself will be commencing in early 1986.

2.3 ENERGY SAVING IN SEWAGE PUMPING

This project was reported in the UK paper at the NATO/CCMS Conference in 1983. Since then the work has been completed with the satisfactory demonstration that savings can be made by modifications in the design and operation of sewage pumping stations. The project examined two different installations, one small and one medium sized.

The first, at a small rural pumping station, showed that 80% of the flow could be delivered at pipe velocities of 0.4 metres/second, provided the remainder is delivered in excess of 0.9 m/s, without problems of deposition or slime growth in the pipeline. The recommended minimum pumping velocity for a single rate pumping system is 0.76 m/s. Savings due to reduced friction head exceeded 25% on a bill of £1,600 ($2,200) annually.

At a larger urban pumping station, a microprocessor was used to control the pumps according to a flow-balancing algorithm, this saved energy equal to £3,200 pa ($4,500) and increased the use of night-time, off-peak energy to make a total saving of £5,000 pa ($7,000) on a bill of £35,000 pa ($50,000 or about 14%). The experimental system is now being replaced by a permanent system by the Wessex Water Authority. The Water Research Centre is negotiating to license the FLOBAL control software for inclusion in a commercial computerized pump controller. Work is under way to extend the algorithm to optimise pumping against a tidally varying head (2).

As an additional aid to design engineers a computer program has been developed to help to optimise the selection of pumps for sewage pumping stations. The program will perform all the necessary calculations to size the pumps for a specified duty, and it then selects the pump with the optimum efficiency from a pump data-base. The program uses inter-active graphics and produces hard copy of pump curves and the selected design data for inclusion in procurement specifications.

2.4. THE "CAPTOR" PROCESS

The project was reported in detail in the 1983 NATO/CCMS paper, and details of the process have been given elsewhere (3, 4). It is a joint project with funding from the Water Research Centre, the Severn-Trent Water Authority (STWA), Simon-Hartley Limited, the UK Department of Trade & Industry and the US EPA.

The current objective of the project is to evaluate a CAPTOR installation at the Severn-Trent Water Authority's full-scale STP at Freehold. The CAPTOR installation (Figure 1) is being used as a pre-treatment stage to reduce a substantial proportion of the BOD load so that the subsequent activated sludge stage can be operated with a greater sludge age and thus achieve nitrification.

So far about 50% removal of dissolved BOD has been achieved in the initial CAPTOR stage but it has been found that a significant proportion of the biomass in the CAPTOR sponge-particles disengages and passes forwards into the activated sludge stage thus reducing sludge age and the concentration of nitrifiers.

The CAPTOR process enables us to double the activated sludge concentration in the aeration stage but laboratory evidence suggests that the activity is only about 50% of non-captured sludge. The nett effect is therefore relatively little different from conventional AS systems.

Pilot-scale work has been started since the last report with the objectives of examining

(i) the use of CAPTOR sponge particles to enhance biomass concentration in the secondary process; and

(ii) the use of CAPTOR sponge particles as a tertiary stage for nitrification which currently looks promising.

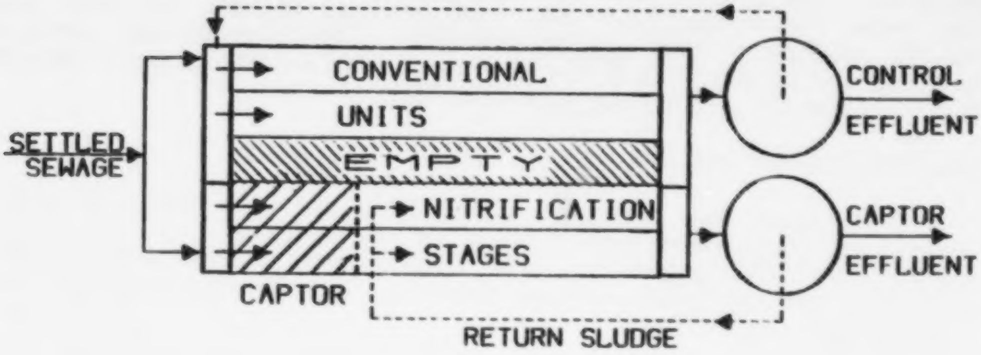

Figure 1. Diagram of the arrangements made at Freehold WRW to uprate the activated sludge plant using CAPTOR and allow its evaluation.

2.5 NITRIFICATION OF A SECONDARY SEWAGE EFFLUENT IN A BIOLOGICAL FLUIDISED BED (BFB)

The intention to establish a plant at the Horley Works of the Thames Water Authority was reported in the 1983 NATO/CCMS paper following small-scale tests by the Authority at its Beckton STP. This work indicated that it was possible to remove about 30 mg NH_3-N/l in a reactor with a retention time of 35 minutes.

The process has recently been tested on a much larger scale in a joint development project with the Water Research Centre, Thames Water Authority and Dorr-Oliver Ltd at the Horley Sewage Treatment Works (South of London) of the Thames Water Authority. The pilot plant (1.83 m x 1.22 m x 5.4 m high) had previously been used in carbonaceous oxidation and nitrification tests at the Water Research Centre's former Coleshill Experimental Site. The pilot plant layout is shown in Figure 2.

The plant has been operated at three different ammonia loading rates for extended periods to determine the optimum performance. During the latter part of 1985 the plant will be operated over a diurnal flow pattern.

The results of the plant performance at the design flow rate is shown in Table 1. It has not been found necessary to sand clean when operating under nitrifying conditions.

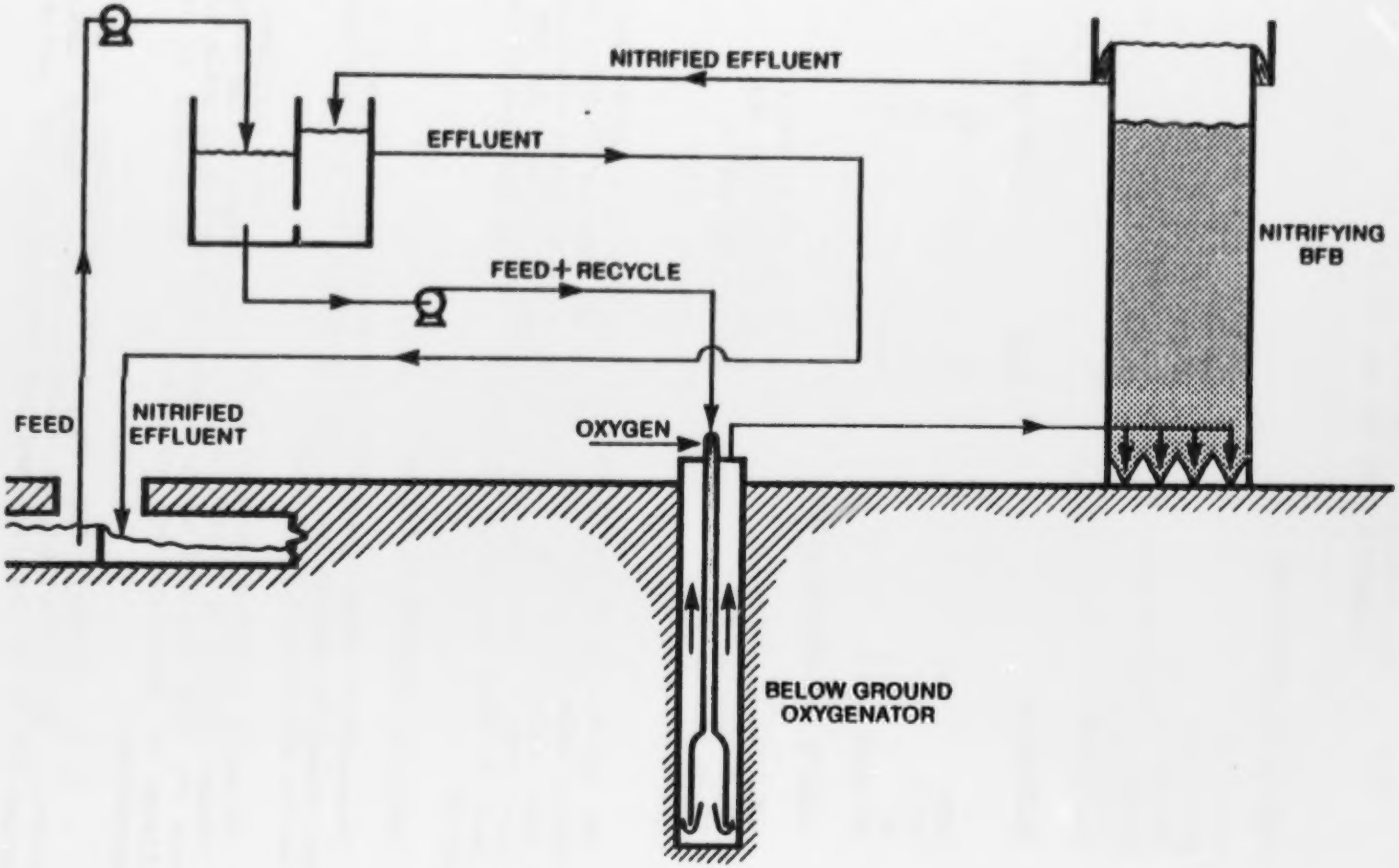
NITRIFIED EFFLUENT
EFFLUENT
NITRIFYING
BFB
FEED + RECYCLE
FEED
NITRIFIED
EFFLUENT
OXYGEN
BELOW GROUND
OXYGENATOR

Figure 2. Flow sheet for the nitrifying BFB at Horley STW.

TABLE 1. PERFORMANCE OF NITRIFYING BFB AT HORLEY STW
(AVERAGE VALUES FOR THE PERIOD)

Operational conditions

Feed flow	370 m^3/d (1700 pe)
Bed volume	9.8 m^3
Superficial HRT	38 min
Biomass concentration	8.1 g BTS/l
Temperature	17.9°C
Run length	69 d

Performance

		Feed	Effluent
BOD_5	mg/l	18	12
NH_3.N	mg/l	27	3
SS	mg/l	30	23
pH value	mg/l	6.8	6.1

Loading and removal rates

BOD loading rate	0.084 kg BOD/kg BTS.d
NH_3-N removal rate	0.112 kg NH_3-N/kg BTS.d
NH_3-N removal rate	0.91 kg NH_3-N/m^3.d

The work has shown the process is feasible on a larger scale. Cost evaluations done during the project have shown that the BFB has a much lower (60% less) capital cost than a comparable activated sludge extension but the operating cost is higher because of the cost of oxygen. The BFB is about 10% lower in total cost using DCF analysis, but is sensitive to the cost of oxygen (5).

2.6. ANAEROBIC TREATMENT OF SEWAGE

Fermentation using anaerobic (methane-forming) bacteria to convert oxygen demand to methane has proved successful for the treatment of food processing and agricultural wastes.

Following pioneering studies in Holland (6) using enrichment cultures of methane bacteria at 12-20°C and laboratory trials at the Water Research Centre (7) using digested sewage sludges at 20°C, pilot-scale trials were initiated to determine the performance of the process at UK ambient temperatures.

A 30 m^3 capacity UASB reactor was constructed at the Stevenage Laboratory by converting an existing sewage storage tank; it was commissioned in Spring 1984 and fed continuously with settled domestic sewage.

We had operational problems with the design of the gas collection/sludge settlement system (which does not allow free passage of settled solids back to the fermentation zone) and with the low methanogenic activities of the digested sewage sludges used for inoculation, but otherwise the mechanical and hydraulic performance of the plant proved satisfactory and entirely trouble-free.

The level of BOD reduction was disappointing and appeared to be severely limited by the relatively low temperatures of the incoming sewage. During the summer and autumn of 1984 purification efficiencies were 27-46% at hydraulic retention times of 12-48 hours and sewage temperatures of 15-20oC. During the winter of 1984/85, sewage temperatures fell to 10oC, fermentation ceased and purification efficiencies fell to zero.

The reactor was reinoculated with digested sludge in the summer and trials will continue until December 1985.

2.7 MODIFIED ROTATING BIOLOGICAL CONTACTOR (RBC) SYSTEM

Problems have been encountered in RBC plants - especially on small flows - as a result of uneven growth of biomass on the discs. The Water Research Centre developed a technique for overcoming this problem which is currently the subject of a patent application.

A joint project has been established between the Water Research Centre, the Wessex Water Authority and Dewplan (ET) Ltd to develop, construct and evaluate a prototype WRc RBC on a Wessex Water Authority site. The operation of the prototype commenced during the first quarter of 1985. There were initial mechanical problems to be overcome and although soluble BOD is satisfactorily removed the unit's mode of operation tends to cause a higher level of solids to appear in the treated effluent. These problems are being currently addressed.

2.8 BIOLOGICAL FILTRATION OF FINELY-SCREENED SEWAGE (THE "LOSLUJ"® PROCESS)

The cost of sludge treatment and disposal in the UK is typically about 45% of the total cost of running a sewage treatment works. One approach towards reducing this cost is to thicken sludge prior to treatment and disposal. An alternative approach is to modify sewage treatment in order to produce less sludge. About two thirds of the total sludge production is derived from primary sedimentation, and if this stage could be eliminated total sludge production could be reduced provided the settleable solids were biologically oxidised in the secondary treatment stage. This approach is not economically attractive in activated sludge plants because of the increased energy consumption required to oxidise the additional solids load. However, in biological filtration plants the oxygen consumed in destroying the solids is provided by natural convection at no cost.

The operating costs of this biological filtration treatment show a reduction of approximately 45% compared with traditional biological filtration. In this method sewage is finely screened (about 1.5 mm aperture size) to remove large particles before being treated in a filter containing a specially developed high voidage plastic medium. The screened sewage is discharged to the filter via a self-cleaning distributor (also developed by WRc). Final clarification takes place in a conventional humus tank.

This method has been successfully demonstrated on a large pilot scale installation which showed that total sludge production was reduced by 45%. Estimates of costs for a typical works of 5,000 population indicate savings of about 30% for capital and 20% for operating costs.

A full-scale installation is under construction for the Welsh Water Authority and two further plants are being designed.

2.9 THE SEWAGE TREATMENT OPTIMISATION MODEL (STOM)

The UK water authorities spend around £150M pa to construct and extend sewage treatment works, and about £300M pa on operating the works. STOM provides these water authorities with a means to:

a) assess the performance of existing works, to allow any remedial measures to be targetted more effectively on those works and processes which are in need of improvement,

b) check the effectiveness and costs of proposed extensions or complete new works, so that satisfactory performance is achieved without over-design,

c) predict the effects of long-term trends in operating conditions so that a view can be taken of the plant's future capability and any plant changes can be planned well in advance.

The Sewage Treatment Optimisation Model (STOM) is a complex computer program developed by the Water Research Centre following an initiative by the British Construction Industry Research & Information Association, and is now in routine use by the UK water undertakings, consultants and universities. It offers a flexible means of modelling performance and costs for groups of processes at sewage works. The model contains modules for individual treatment processes such as activated sludge, biological filtration, anaerobic digestion, and auxiliary processes such as flow mixing and division. Each module relates performance and costs to design and operation; most of the common processes are included. The user links the corresponding modules together to represent a complete works.

The model is under continuous development involving both the addition of modules for further processes and enhancement of existing modules. Models for some processes have yet to be included (e.g. rotating biological contactors and tertiary treatment). Currently a module for the performance of tertiary rapid sand filtration, prepared in co-operation with Imperial College, London, is being evaluated for eventual inclusion in the model.

The standard capital and operating costs in STOM are updated from their 1976 base by government cost indices, although the user can substitute his own costs. The cost indices do not take into account changes in operating and maintenance practices since 1976 (e.g. the replacement of resident staff by mobile gangs). A detailed manual containing all the formulae and parameters used in the model has also been prepared.

3. BIOLOGICAL SLUDGE TREATMENT AND HANDLING

3.1 AEROBIC DIGESTION OF SLUDGE

When aerobic conditions are maintained in sewage sludge, exothermic reactions take place and the temperature of the sludge can rise to 55°C or higher in a well lagged tank. This increase in temperature offers an opportunity to reduce the retention times required to achieve stabilisation and/or to achieve a disinfection.

Successful aerobic digestion using pure oxygen and subsequently using air was reported in the 1983 NATO/CCMS paper. Costs when using oxygen were unacceptably high, but further work showed that the process was viable and economically attractive when air was used to maintain aerobic conditions. It has been established that the layer of foam which builds up on top of the sludge is critical in achieving very high oxygen utilisation efficiencies from air and recent work has concentrated upon more detailed evaluation of foam management techniques. Economic comparisons show that the process could be competitive with alternative methods of pre-treatment prior to anaerobic digestion for producing a disinfected sludge should this prove to be necessary.

The next stage of this project will consist of a joint evaluation of a technique developed in Switzerland in which aerobic digestion is followed by anaerobic digestion. This technique appears to produce a sludge in which all pathogens have been killed or deactivated and which readily consolidates to thicknesses of 8-10%.

3.2 SUBMERGED COMBUSTION OF DIGESTER GAS FOR PRE-PASTEURISATION OF SLUDGE

An alternative method to aerobic digestion of achieving a disinfected and stable sludge is to pre-heat the sludge to about 65°C by burning digester gas in a submerged combustion device. The hot sludge is then cooled and anaerobically digested at about 35°C.

The joint project reported in the 1983 NATO/CCMS paper encountered problems with the submerged combustion equipment and this resulted in delays. These were eventually overcome and sufficient data were obtained for the design of a full-scale system. The full-scale (20,000 pop) demonstration plant comprising automatic primary tank desludging, consolidation thickening, submerged combustion pre-pasteurisation, and mesophilic anaerobic digestion has now been designed and is currently being installed in the north of England.

Commissioning will be completed in the first quarter of 1986 when a 12 month intensive monitoring programme of the plant performance and microbiological quality of the sludge will commence.

3.3 DIGESTER GAS UTILISATION

A survey of digester gas utilisation in the UK has recently been completed which shows that of the 1.4 million tonnes dry solids of sewage sludge produced each year in the UK, about 50% is anaerobically digested and produces about 250 x 10^6 m^3 of gas with an energy value of about 10^{10} Joules. This is less than 0.1% of all UK energy needs, but is about 30% of the energy consumption of the UK water industry.

About 30% of digester gas is used for digester heating and 50% is used to generate electrical power for use in sewage works, mainly in dual-fuel engines on large works. Waste heat from the engines is used to heat the digesters.

Minor uses for digester gas include use as a road vehicle fuel (<1%) but this is not an economic proposition. Before use the gas must be scrubbed to remove corrosive sulphides and then compressed.

About 40 x 10^6 m^3 of digester gas is unused each year, mostly on sewage works in the size range 10,000 - 100,000 population, and there has been significant interest recently in installing small packaged spark-ignition engines for combined heat and power generation in these works. Case studies at a small works (10,000 pop) and large works (100,000 pop) is currently being carried out. Results to date show that the economics are very doubtful on works of 10,000 pop or lower, but that at larger sizes of works considerable savings can be made.

3.4 CONSOLIDATION THICKENING

Consolidation under gravity can be a very cheap and cost-effective method of thickening sludges in order to reduce the cost of treatment, transport and disposal. A study undertaken by the Water Research Centre has indicated that savings in operating costs of £15-20M pa ($20-$30 million) could be achieved in the UK by the planned use of consolidation thickening of sewage sludges.

Consolidation thickening of sludges is an apparently simple process. The sludge is held in a tank and consolidation takes place under the influence of gravity as the sludge is compressed under its own weight forcing the interstitial water within the sludge into the supernatant liquid above. The performance of the process depends upon a number of factors including the sludge blanket height, sludge retention time, the method of operation (i.e. batch or continuous), and the design and operation of mechanical aids including picket fences. The sludge height and retention time, in particular, are critically dependent upon the properties and characteristics of the particular sludge but until now there has been no reliable method of relating tank dimensions and sludge characteristics to plant performance. Consequently, many thickening tanks perform poorly, and it is not uncommon to see sludge solids floating rather than consolidating.

Theoretical and full-scale plant studies have led to an improved understanding of the fundamental mechanisms involved in consolidation thickening. Consolidation can be predicted from three easily measured sludge parameters, the Compression Coefficient, Compression Index and the Resistance to Consolidation which can be measured in the laboratory using specially developed procedures.

A mathematical model programmed into a computer handles the data to produce performance curves showing how sludge blanket height and sludge retention time affect the solids concentration in the output sludge. A family of curves is produced depending on the mode of operation of the thickener, i.e. batch or continuous. These performance curves enable the engineer to select with confidence an appropriate combination of the sludge blanket height, tank diameter and method of operation to give the required performance.

Picket fences and effective process control are essential for optimum performance and further experimental work has shown how these components should be designed and operated.

This design procedure has already been used to produce process designs and plant specifications for a wide range of sludges, and in most cases the size and shape of thickener has been suitable for prefabricated construction methods using steel tanks. Several full-scale demonstration plants are being installed and the first to come on-line was commissioned early in 1985 and produces a thickened sludge of about 12% solids from a primary sludge feed of about 4% solids.

3.5 FILTER PRESSING CONTROL

The 1983 NATO/CCMS paper described a co-operative project between the Severn-Trent Water Authority and the Water Research Centre which had as its objective the automation and optimisation of sludge filter-pressing. This project is now nearing completion and a study has shown that potential savings in the UK are in the region of £5M.

About 30% of UK sludge is chemically conditioned and dewatered, mostly in filter plate presses. The operating cost is about £25M pa and the process is expensive, the major elements of cost being chemicals and labour, which each account for nearly 50% of total operating costs.

The microprocessor-based process control system which has been developed has achieved a reduction in the costs of both labour and chemicals of about 50% on the full-scale installation at the Severn-Trent Water Authority's Mansfield STP.

The essential features of this system are:

- Accurate and efficient chemical dosing over the wide variation in sludge flow rate that occurs during the pressing cycle.
- Control of press feed pumps to achieve and maintain optimum conditions throughout the press cycle.
- Continuous monitoring of cake quality and termination of the pressing cycle when adequate product quality has been achieved.

Chemical conditioning and filter pressing are thereby made very competitive with other sludge treatment and disposal routes. The process management system is now commercially available and it is being installed at several other sites.

3.6 OIL FROM SLUDGE

The UK water industry currently operates a well managed system of sludge treatment and disposal that takes due account of environmental protection. However, looking to the long-term future it is essential to consider alternative sludge treatment and disposal routes that could either be cheaper than current methods or could meet new targets for environmental constraints in the most cost effective manner.

Against this background the Water Research Centre is evaluating a number of Long Term Options for alternative sewage sludge treatment and disposal routes. Any radical alternative approach is likely to be economic only if some of the resource-value of sludge can be offset against processing costs. Any financial value a raw sludge may have is associated mostly with its fat and protein content and there are many strategies available for tapping this resource. A preliminary desk study showed that thermochemical processing of sludges to produce fuels was potentially attractive, and that slow pyrolysis was amongst the processes that warranted further investigation.

Professor Bayer in Germany has already shown that it is technically possible to convert by pyrolysis much of the organic matter in sewage sludge to oil and char with both products having potential value as a fuel. Comprehensive process design and economic studies have recently been completed of a pyrolysis route for both raw and digested sludges using UK cost data.

The process flow sheet is potentially complex (see Figure 3) and a process model has been developed to study the interaction between the various process stages, and to evaluate the numerous options for heat recovery within the process route.

These studies indicate that the process could be very competitive with incineration (see Figure 4) but it is important to note that the capital and operating costs of the pyrolysis stage are only a small fraction (less than 10%) of the total route costs, and therefore the economical viability of the

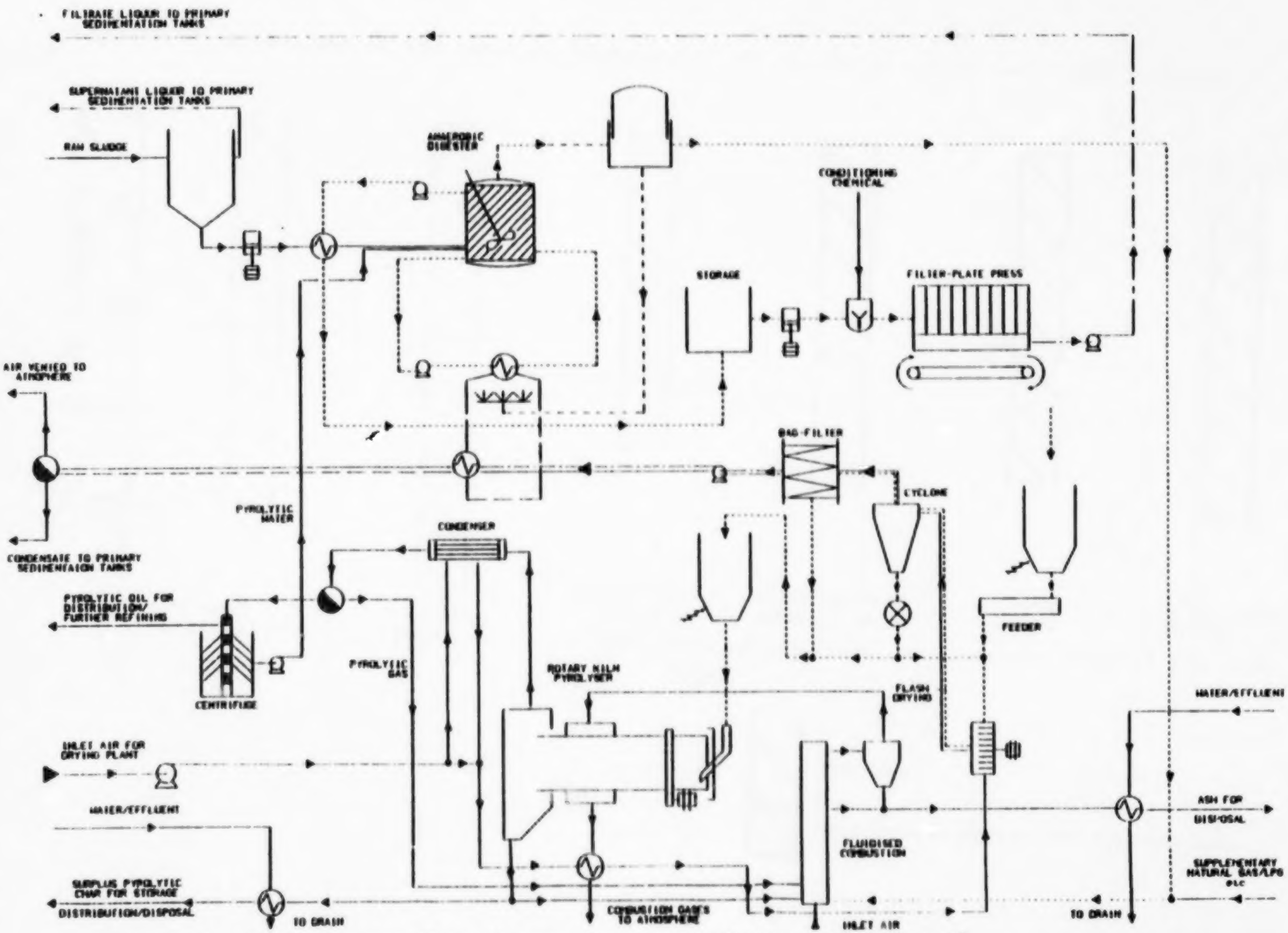
FILTRATE LIQUOR TO PRIMARY SEDIMENTATION TANKS
SUPERNATANT LIQUOR TO PRIMARY SEDIMENTATION TANKS
RAW SLUDGE
ANAEROBIC DIGESTER
CONDITIONING CHEMICAL
STORAGE
FILTER-PLATE PRESS
AIR VENTED TO ATMOSPHERE
CONDENSATE TO PRIMARY SEDIMENTATION TANKS
BAG-FILTER
CYCLONE
PYROLYTIC WATER
CONDENSER
PYROLYTIC OIL FOR DISTRIBUTION/ FURTHER REFINING
CENTRIFUGE
PYROLYTIC GAS
ROTARY KILN PYROLYSER
FEEDER
FLASH DRYING
INLET AIR FOR DRYING PLANT
WATER/EFFLUENT
WATER/EFFLUENT
ASH FOR DISPOSAL
FLUIDISED COMBUSTION
SUPPLEMENTARY NATURAL GAS/LPG etc
SURPLUS PYROLYTIC CHAR FOR STORAGE DISTRIBUTION/DISPOSAL
TO DRAIN
COMBUSTION GASES TO ATMOSPHERE
INLET AIR
TO DRAIN

Figure 3. Draft process flow diagram for the pyrolytic processing of anaerobically digested sewage sludge.

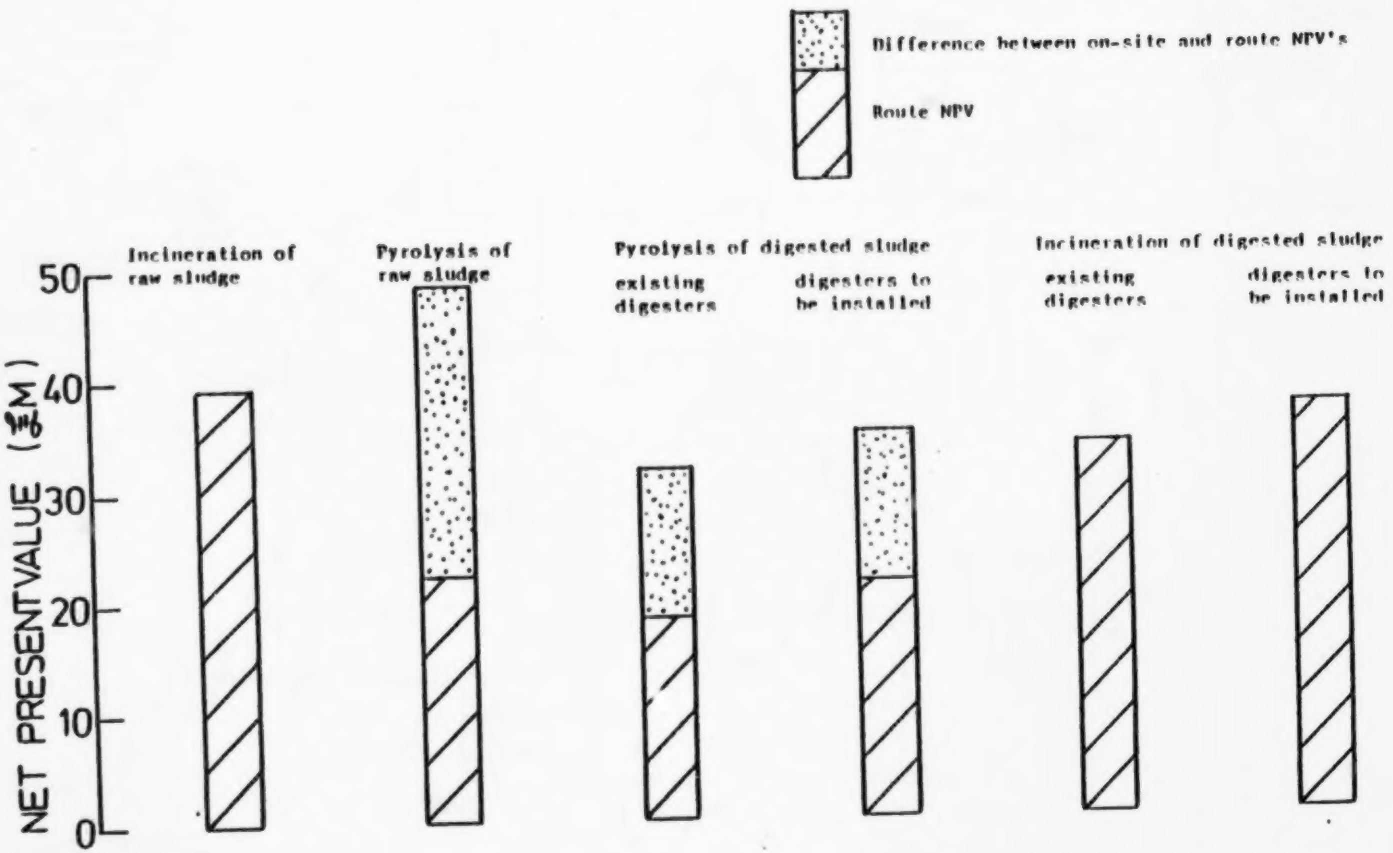

Figure 4. Comparison of the costs of incineration and pyrolysis routes for sludge disposal.

process lies in optimising the total route and not simply concentrating effort upon the reactor design. Route costs are critically dependent upon the following:

(i) Process route energy demand.

Critical areas are the energy required for drying and the measures taken for heat recovery between the various process stages. The energy for drying depends upon the performance of the pre-thickening, dewatering and drying stages.

(ii) Anaerobic digestion.

Whilst the quantity of oil produced from raw sludge is substantially greater than that produced from digested sludge a desk study has shown that this advantage is more than offset by the greater on-site costs of processing raw sludge. This is due, in part, to the reduction in quantity of sludge solids passing forward for processing, and hence a reduction in capital cost of downstream plant. There are also savings in fuel costs due to the reduced load on the drying stage. Furthermore, the inclusion of anaerobic digestion considerably increases the scope for cost-effective recovery of low grade heat, which further reduces the need to burn primary fuel.

(iii) The value of the pyrolytic oil produced.

The studies being carried out by the Water Research Centre are complementary to the work being undertaken at the Wastewater Technology Centre in Burlington Ontario with whom there has been regular contact. It is hoped that these contacts will be strengthened into more formal arrangements for collaboration.

3.7 INSTRUMENTAL ANALYSIS OF BIOGAS

Studies are being undertaken to develop new and improved strategies for the monitoring and control of the anaerobic digestion process, based on detailed analysis of the composition of the biogas produced.

Theoretical (mathematical modelling) studies of the microbial ecology of the fermentation (8) identified hydrogen (H_2) as a key intermediate in the conversion of organic matter to methane and trials are now in progress to determine whether on-line monitoring of H_2 in biogas can be used to detect small fluctuations in the performance of the anaerobic digestion process.

Typical concentrations of hydrogen in the biogas from sewage sludge digesters are 36-220 vpm (parts per million by volume (average 73 vpm).

At one particular works, a comparison was made between the start-up of two identical new digesters. Late modifications and last-minute "teething-troubles" during the commission of one digester caused the concentration of hydrogen in the biogas to rise to 240 vpm before settling down to a baseline value of 60 vpm. In the other digester, the modifications were completed before commissioning and the concentration of hydrogen in the biogas remained at 40 - 80 vpm throughout.

The extreme sensitivity of the analysis can be seen from Figure 5 which shows the changes in hydrogen content of the biogas from one of these digesters during its hourly feeding cycle (9).

4. OPERATIONAL AIDS

4.1 DESLUDGING OF SEDIMENTATION TANKS

In order to reduce significantly the frequency of visits by mobile gangs to unmanned sewage treatment works, automatic control of sedimentation tank desludging is essential. Following extensive field trials carried out in association with the Thames and Anglian Water Authorities it has been established that simple timer-only control is rarely satisfactory since it results in blockages or in the production of very thin sludges.

Using existing equipment a microprocessor based control system has been developed which has been used satisfactorily over many months. Control is achieved by a combination of timing and monitoring of sludge blanket level in the tanks.

As a result of this work, a commercial unit has been developed and is undergoing field trials. This unit offers a choice of desludging pumps and a range of sensing devices to deal with most situations likely to be met on small to medium sized works (less than 10,000 population equivalent).

4.2 MANAGEMENT OF SMALL DISPERSED UNMANNED STP

Following a joint study undertaken by the Water Research Centre with the Anglian Water Authority to develop an ICA based operating strategy for some 150 sewage pumping stations and 50 treatment works, it was decided to implement the proposed scheme on a pilot scale before proceeding with the full scheme.

The pilot scheme has now been completed and encompasses a biological treatment works, an oxidation ditch treatment works and a pumping station each equipped with micro-processor based outstations and appropriate Instrumentation, Control & Automation (ICA) equipment and connected via a telemetry network (representative of that proposed for the full scheme) to a master-station at the Central Operations Room. The master station is based upon a DEC LSI11/23 computer but nevertheless has software which provides full management information facilities. Data and operating experience collected from the pilot system is now being used for the final designs for the full-scale scheme.

The results obtained will be used in a Guideline for the development of a process management system for dispersed works.

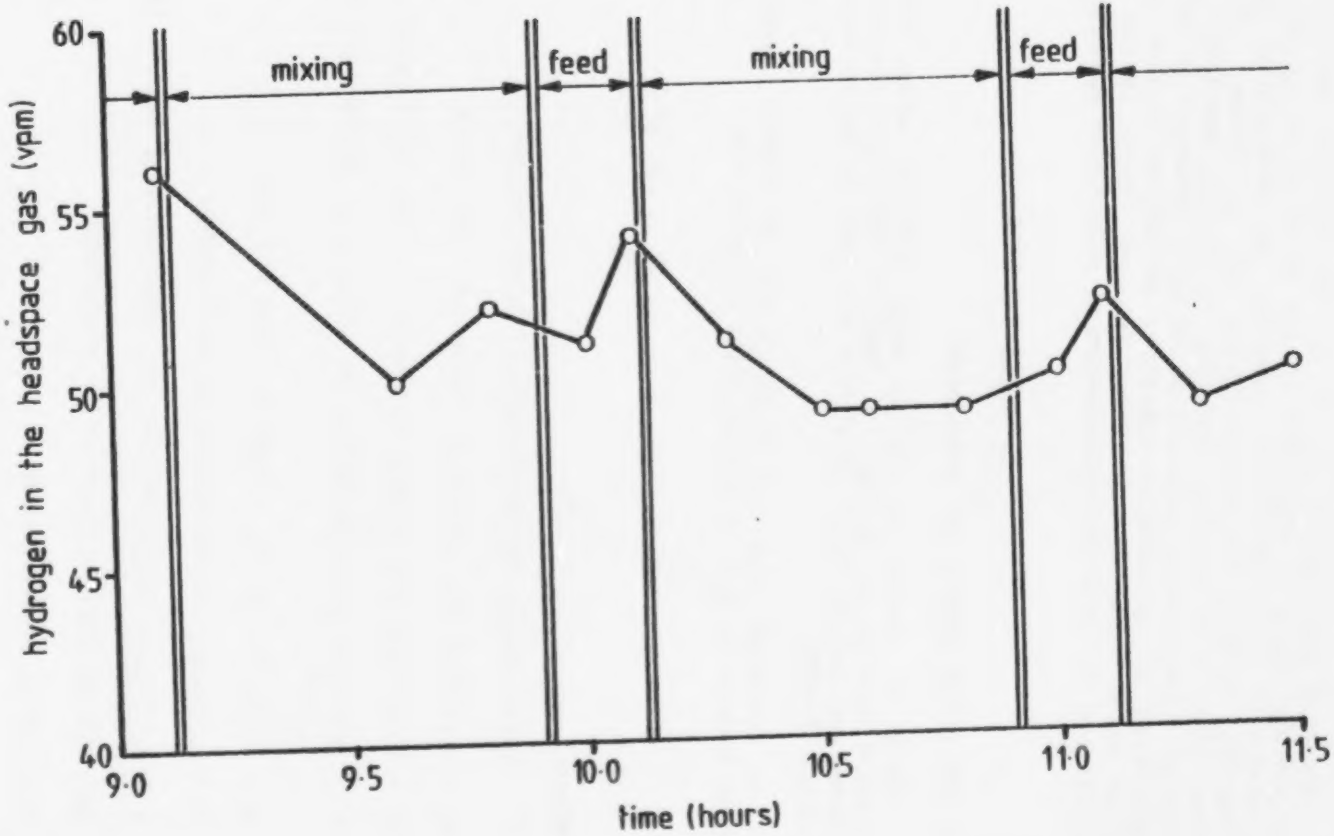

Figure 5. Variations in the concentration of hydrogen in the headspace gas during the feed cycle of an anaerobic sludge digester.

4.3 MAINTENANCE SIMULATION STUDIES

The study described in section 4.2 and the resulting pilot evaluation have provided valuable experience in the selection of operating strategies for groups of dispersed works. However, the selection of an appropriate maintenance strategy is nearly always left to chance. Following some success using a simulation technique (originally developed for study of production line queueing problems in the motor industry) in the study of the consequences of alternative operating strategies carried out with the Anglian Water Authority, the Water Research Centre is now applying the technique to the study and optimisation of maintenance strategies.

5. MANAGEMENT AIDS

5.1 PER CAPITA SEWAGE LOAD ASSESSMENT

There is concern in the UK water industry about the accuracy of available data on the strength of domestic sewage and the volume of sewage produced per person since these data are used in the calculation of trade effluent charges.

In agreement with the Confederation of British Industry (CBI) the Mogden formula is used as the basis for charging, viz.

$$C = R + V + S.\frac{Sw}{Ss} + B.\frac{Ow}{Os}$$

Where

C = total charge per cubic metre of trade effluent

R = reception and conveyance charge per cubic metre

V = volumetric and primary treatment cost per cubic metre

S = treatment and disposal costs of primary sludges per cubic metre of sewage

Sw = suspended solids content of trade effluent

Ss = suspended solids content of crude sewage

B = biological oxidation cost per cubic metre of settled sewage

Ow = COD of trade effluent after settlement

Os = COD of settled sewage

In response to this concern, the Water Research Centre is undertaking a project to assess the contribution per head of population to the flow and strength of domestic sewage. The project will provide the necessary up-to-date information to enable the water authorities to set firmly based and readily defensible trade effluent charges.

The data generated by the project will also be useful to the water authorities in connection with performance measurement.

The project, which is due to start in the third quarter of 1985, consists of a scheduled programme of sampling and analysis, over a 12 month period, of sewage from a residential catchment which is entirely domestic except for a small number of retail shops. The sewer from the catchment passes under the Water Research Centre's Stevenage site. Flow measuring facilities have been installed to permit flow related analysis. The study will cover diurnal, hebdomadal and seasonal variations in flow and strength. The sewerage system is a separate one and will permit the study of the effects of storm flows and of infiltration. The catchment is well defined and accurate population figures are available. Demographic data are available from census returns and these will be used for data analysis.

The variables being determined include BOD, COD, suspended matter, settleable matter, total organic carbon, ammonia, Kjeldahl nitrogen, nitrite, nitrate, orthophosphate and chloride.

A similar study was carried out on the same sewer in 1956-57 and thus it will be possible to see what changes have occurred during the 29-year intervening period.

5.2 COST PERFORMANCE INDICES STUDY

A useful management tool is the setting of performance targets. In wastewater treatment this can take the form of setting targets for the quality of the treated effluent and for the total running costs of the treatment plant. The former is set by reference to environmental quality objectives, or - in some countries - by legislation or directive. Quality targets are relatively easy to set and monitor since they can be defined numerically in terms of well established variables (e.g. concentrations of BOD, NH_3 etc).

However, operating-cost targets are more difficult to set. There is relatively little data available to guide managers in assessing whether or not a sewage treatment plant is operating as efficiently as it might. There are many factors which affect the operating cost, and similar plants treating similar sewage may justifiably have very different operating costs. The problem becomes more difficult if the manager has a number of different types of treatment plant under his control (e.g. activated sludge, biological filters, RBC etc) and cannot therefore compare the costs of similar processes.

In an attempt to improve efficiency water authorities in the UK have asked for guidance on target costs for the operation of treatment plant. A co-operative project has therefore been established by the Water Research Centre, involving all ten UK water authorities, in which operating cost data are being collected for the majority of sewage treatment plants in England and Wales. These data are then collated and analysed making it possible to produce median costs for plants of similar types and size. These data then allow managers to identify plants whose operating costs lie outside the norm and then to evaluate the reasons for the performance. Since the data are held in a large database with facilities for data manipulation it is possible to make individual comparisons between specified plants, groups of plants, different regions, different processes etc. This will enable managers to set more realistic cost-performance targets.

A further objective of the project is to enable the Water Research Centre to identify areas of greatest cost and thus to develop R & D projects with the best potential for savings. It will also help to identify the most efficient plants which can then be evaluated to provide guidelines for the operators of other treatment plant.

5.3 FIELD EVALUATION OF INSTRUMENTS

The 1983 NATO/CCMS paper reported on the development of this project which is designed to obtain "the cost of ownership" of instruments used in the water industry and thus to enable management to ensure that the best instruments are bought for any specified application. An important criterion is that the test fluids and test environment should be those for which the instruments will normally be bought rather than in a laboratory environment with clean water as the test fluid.

Two full-scale test facilities have now been established in the UK with partial funding from the Department of Trade & Industry. The first Evaluation and Development Facility (EDF) was opened early in 1985 at the Witney STP of the Thames Water Authority. The second EDF was opened in early June at the Eccup Drinking Water Treatment Plant of the Yorkshire Water Authority. The former EDF provides evaluation facilities for instruments for sewage treatment plant, whilst the latter EDF will take instruments intended for use in Drinking Water Plant.

A careful testing and evaluation protocol has been developed which has been discussed with a number of organisations including the IAWPRC so that reports on instruments tested at one of the UK EDF's may have validity internationally. Already instruments from a number of countries, including the UK, have been submitted to the Water Research Centre for evaluation and are currently being evaluated under field conditions at the EDF for a 12 month period, relevant data being logged automatically via the on-site computer system for later off-line analysis on the Water Research Centre's own computer facilities.

A concise report is produced for each instrument detailing the results and findings of the evaluation and providing an indication of the total cost of ownership, taking into account:-

accuracy
reliability
response times
maintenance needs
calibration
cleaning
construction
ease of use.

These reports are made available to potential users in the Water Industry to assist them in equipment selection. Benefits to manufacturers include reference to reports in publicity material and the feedback of valuable field test data to the design and marketability of the instruments.

In the first year of tests, up to ten instruments are being evaluated in each of the following categories:

activated sludge flow measurement
crude sewage flow measurement
open channel flow measurement
ammonia measurement.

Evaluation of DO measuring instruments will commence shortly with further test programmes being introduced at regular intervals over the next few years.

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6. APPENDIX

A SELECTION OF UNIVERSITY DEPARTMENT RESEARCH PROJECTS RELEVANT TO WASTEWATER TREATMENT

Institution	Project description	Principal Researcher
University of London Imperial College of Science and Technology	Risk analysis in planning and design of wastewater treatment processes in both the developed and developing countries. Modelling, forecasting and real-time control of wastewater treatment processes.	Jowitt, P W
	Dynamic modelling and design of waste stabilisation ponds.	Lumbers, J P
	Analysis and removal of herbicides and related materials in wastewater treatment processes. Behaviour of nitrilo triacetic acid in sewage and sludge treatment systems.	Perry, R
	Design and performance of rotating biological contactors.	Lumbers, J P
University of Leeds	Anaerobic treatment of high-strength waste water in a fixed film system.	Stentiford, E I
	Use of immobilised whole cells in the treatment of domestic and industrial wastewaters. Role of extra cellular poly-saccharides in sludge flocculation and sludge bulking.	Horan, N J
University of Birmingham	Use of aerated lagoons for industrial wastewater treatment.	Tebbutt, T H Y
	Stable foams in activated sludge process. Flocculation and attachment in anaerobic systems.	Forster, C F

Trent Polytechnic	Degradation of stored treated and untreated wastewater prior to its use in the flushing of household toilets.	Ferris, S A
Paisley College of Technology	Sludge activity measurements in biological oxidation of wastewaters.	Clark, J H
University of Newcastle upon Tyne	Mathematical modelling of the scale-up of aerobic reactors for wastewater treatment.	Shaaban, M G B
	Attachment of bacteria to solid surfaces in anaerobic wastewater filters.	Sanderson, J A
	Evaluation of performance and mathematical modelling of anaerobic rotating biological contactors for wastewater treatment.	Echaroj, S
University of Manchester Institute of Science and Technology	Fluidised bed fermentation; applications in aseptic fermentation and wastewater treatment. Supported biomass in reactors; hold-ups, substrate uptake, product formation.	Black, G M
Loughborough University of Technology	Design formula for aerated lagoon wastewater treatment.	Ellis, K V
University of Surrey	Inhibiting conditions in biological removal of nitrogenous pollutants from wastewater.	Winkler, M A
University of York	Development of attached microbial film process variants for wastewater treatment; relationship between biochemical activity and population structure in activated sludge systems.	Davies, M

University of Oxford	Characterisation of insoluble compounds of toxic elements in sewage sludge and sludge treated soil. Decomposition of sewage sludge and character of decomposition products. Study on recovery from sewage of phosphorus usable as fertiliser.	Beckett, P H T
University of Wales Institute of Science & Technology	Control of nuisance flies in sewage filter beds by *Bacillus* thuringiensis.	Dancer, B N
University of Cambridge	Stability of bubble induced circulation of liquid in a deep shaft U-tube sewage treatment plant.	Davidson, J F
University of Exeter	Design of electro-separators for the filtration and thickening of slurries.	Wakeman, R J

ADVANCES IN WASTEWATER TREATMENT AND SLUDGE MANAGEMENT PRACTICES RELATED TO PATHOGEN AND TOXICITY CONTROL

by

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ABSTRACT

Research to support municipal sludge regulations includes the determination of the kinds and concentrations of pathogens in sewage sludge from various wastewater treatment systems and the characterization of the pathogen reduction capabilities of alternative solids handling processes. The extended aeration process produces greater reductions in bacterial densities of waste sludge than conventional aeration and achieves in the waste sludge a one-log reduction in Salmonella. Sludge handling processes, producing significant reduction in pathogens but not disinfecting the sludge, include conventional aerobic digestion, anaerobic digestion, conventional composting and lime stabilization. Processes, producing further reduction in pathogens and disinfecting the sludge, include composting for 3 days at 55°C for within vessel and static pile systems and 15 days at 55°C for windrow systems, heat drying, heat treatment and thermophilic digestion. Autothermal thermophilic aerobic digestion produces especially effective inactivation of Salmonella and total plaque forming units (viruses) in the sludges.

Ultraviolet light (UV) processes for disinfection of wastewater have evolved from the development and demonstration stage to full-scale application with 60 facilities now in operation. UV processes are competitive, if not less expensive, than chlorination. Suitable design approaches and disinfection models have been developed. Operation and maintenance experiences are summarized.

Toxics treatability and control research includes the characterization of removals and effluent concentrations of specific toxics in a range of treatment systems, the determination of the fate of these toxics by the three principal removal mechanisms of sorption, volatilization and biodegradation, and the evaluation of the toxicity reduction capability of treatment systems for the removal of overall toxicity. The toxics removal data indicate that conventional primary-activated sludge treatment provides best overall control of specific toxics. The limited kinetic studies on the specific removal mechanisms suggests that biodegradation in activated sludge systems is the principal removal mechanism for the organics studied but that volatilization of the moderately volatile compounds also is important. Further work is needed to appropriately characterize the three removal mechanisms especially for highly volatile and sorbable toxics. Conventional primary-activated sludge treatment provides good toxicity reduction capabilities for complex mixtures of toxics. The use of biomonitoring methods for toxicity appears to provide a practical method for managing complex mixtures of toxics, especially in municipal wastewaters.

INTRODUCTION

This paper presents recent information and control approaches for pathogens and toxicity in municipal wastewater and sludge process streams. The rationale behind the pathogen control technology standards for municipal sludge application to the land are described together with relevant performance and cost capabilities of the Autothermal Thermophilic Aerobic Digestion Process.

A rational procedure for designing Ultraviolet Radiation facilities for disinfecting wastewaters is described. Observed performance of a full scale operating facility is compared to the performance predicted by the model.

Two approaches, described in this paper, are being used to evaluate and control toxics in wastewater treatment. The first approach using representative specific toxics evaluates overall removals in pilot scale treatment systems and specific removal mechanisms in laboratory studies. The second approach uses bioassay tools for characterizing toxicity control for complex mixtures of unknown toxics.

MUNICIPAL SLUDGE DISPOSAL REGULATIONS

The interim final regulations specifying the criteria for sludge use on land pertaining to disease prevention and pathogen control as required by The Resource Conservation and Recovery Act (RCRA) were published in September 1979 - Code of Federal Regulations (CFR, Title 40, "Criteria for Classification of Solid Waste Disposal Facilities and Practices", Para. 257.3-6, Disease, Interim Final Regulations, Effective October 15, 1979). Farrell (1) described the rationale behind these regulations as being either:

- eliminate the possibility of contact by eliminating the pathogens

- require a series of formalized barriers (including processing to reduce pathogen densities) that insure that the probability of human contact is low. Figure 1 illustrates the management options provided by the regulations for use of sludge on the land.

Two technology-based standards for control are included in the regulations:

- processes to significantly reduce pathogens (PSRP)
- processes to further reduce pathogens (PFRP).

Processes to significantly reduce pathogens are described in Table 1 (1). These technologies provide a one-log reduction of bacterial and viral pathogens. While a two-log reduction in indicator organisms, such as fecal coliform and total coliform densities, is attainable with anaerobic digestion under these operating conditions, the relative reductions in pathogens and indicator organisms varies with each technology.

TABLE 1. PROCESSES TO SIGNIFICANTLY REDUCE PATHOGENS

Technology	Conditions
Aerobic Digestion	60 days @15°C or 40 days @20°C & 38 % volatile solids (V.S.) reduction
Anaerobic Digestion	60 days @20°C to 15 days @35°C - 55°C & 38% V.S. reduction
Composting	5 days @40°C & 4 hours @>55°C
Lime Stabilization	pH 12 & 2 hours contact
Other	Equivalent reduction of pathogens and volatile solids

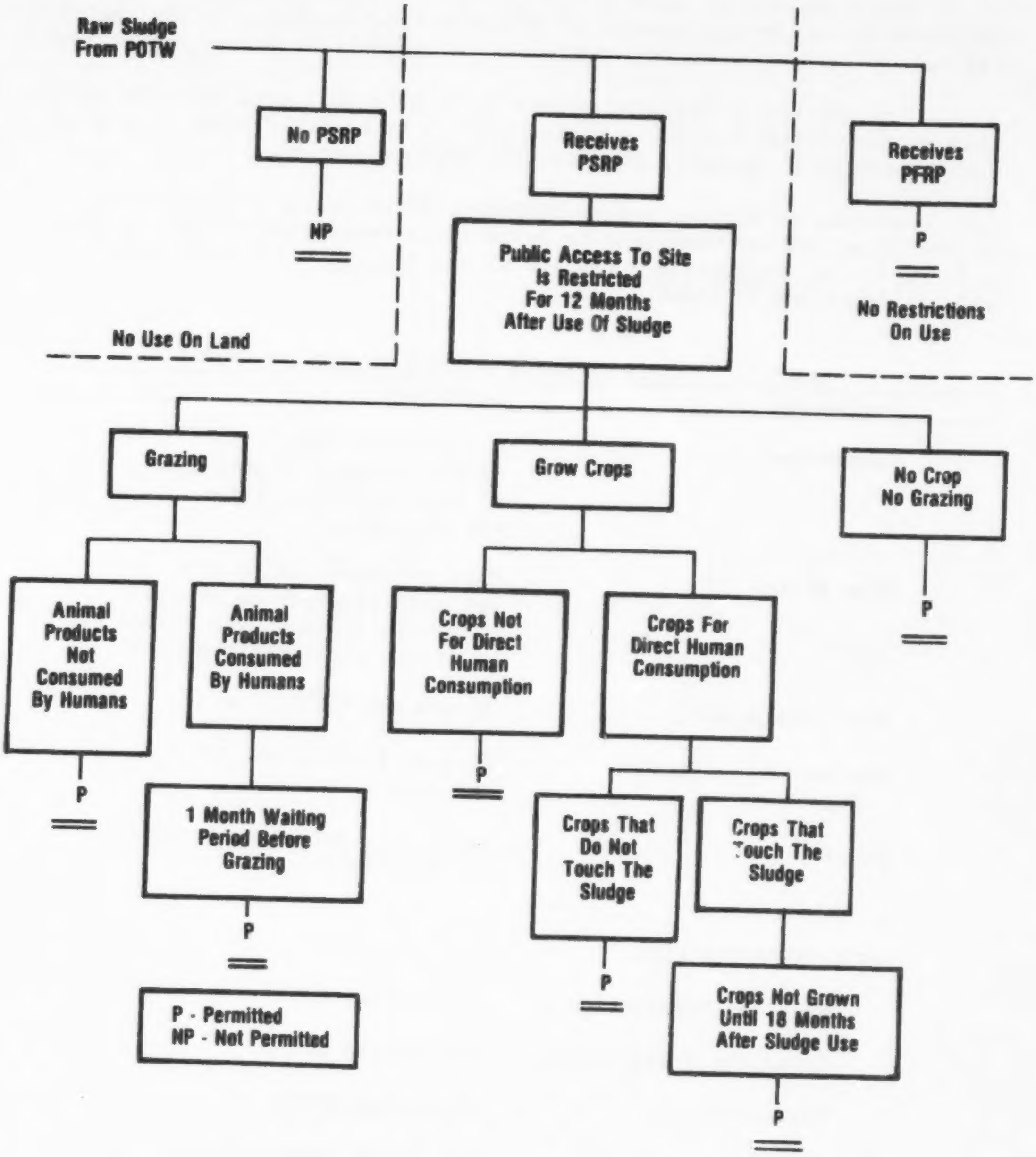

Raw Sludge From POTW
No PSRP
NP
No Use On Land
Receives PSRP
Public Access To Site Is Restricted For 12 Months After Use Of Sludge
Receives PFRP
P
No Restrictions On Use
Grazing
Grow Crops
No Crop No Grazing
P
Animal Products Not Consumed By Humans
P
Animal Products Consumed By Humans
1 Month Waiting Period Before Grazing
P
Crops Not For Direct Human Consumption
P
Crops For Direct Human Consumption
Crops That Do Not Touch The Sludge
P
Crops That Touch The Sludge
Crops Not Grown Until 18 Months After Sludge Use
P
P - Permitted
NP - Not Permitted

Figure 1. RCRA criteria for use of sludge on land (1).

The inability of anaerobic digestion and most of the other PSRP processes to reduce the density of helminth eggs is offset by the restricted access and proper siting considerations identified in the regulations.

In addition to pathogen reduction, PSRP's must eliminate the potential of the sludge to cause a vector problem by either drying the sludge, raising the pH or reducing the odor and organic content.

Processes to further reduce pathogens (PFRP) which disinfect the sludge (i.e., reduce pathogens to below their detectable limits, viruses - 1 PFU/100 ml, Salmonella-3 CFU/100 ml and Ascaris - 1 viable EGG/100 ml) are described in TABLE 2 (1).

TABLE 2. PROCESSES WHICH FURTHER REDUCE PATHOGENS

Technology	Conditions
Composting	3 days @55°C for within vessel & static pile 15 days @55°C & 5 turns for windrow
Heat Drying	Cake moisture <10% & 80°C wet bulb temperature of gas stream in contact with sludge or sludge particles reach 80° C
Heat Treatment	30 minutes @180°C
Thermophilic Aerobic Digestion	10 days @55°C & 38% V.S.S. reduction
Other	Equivalent pathogen & volatile solids reduction
PSRP PROCESSES PLUS	
Beta Ray Irradiation	1.0 Megarad @20°C
Gamma Ray Irradiation	1.0 Megarad @20°C
Pasteurization	30 minutes @70°C
Other	Equivalent pathogen reduction

The U.S. EPA plans to issue revised municipal sludge disposal regulations in 1986 for use of sludge on the land, as well as landfilling, distribution and marketing, incineration and ocean disposal. This regulation development activity has stimulated a high level of interest and effort in characterizing and improving the pathogen reduction capabilities of sludge stabilization processes and practices as well as identifying more cost-effective designs.

Figure 2 from Farrell (2) shows the log of the bacterial densities (no/gram) in the influent wastewater solids from five treatment plants. The bacterial densities are surprisingly consistent. This study was conducted to determine the bacterial content of the waste activated sludge from extended aeration-type facilities. Figure 3 shows that this type of facility is capable of achieving greater reductions in bacterial densities than conventional treatment facilities and a one-log reduction in Salmonella. The current sludge regulations, however, require a separate sludge processing step which achieves an additional one-log reduction in pathogens.

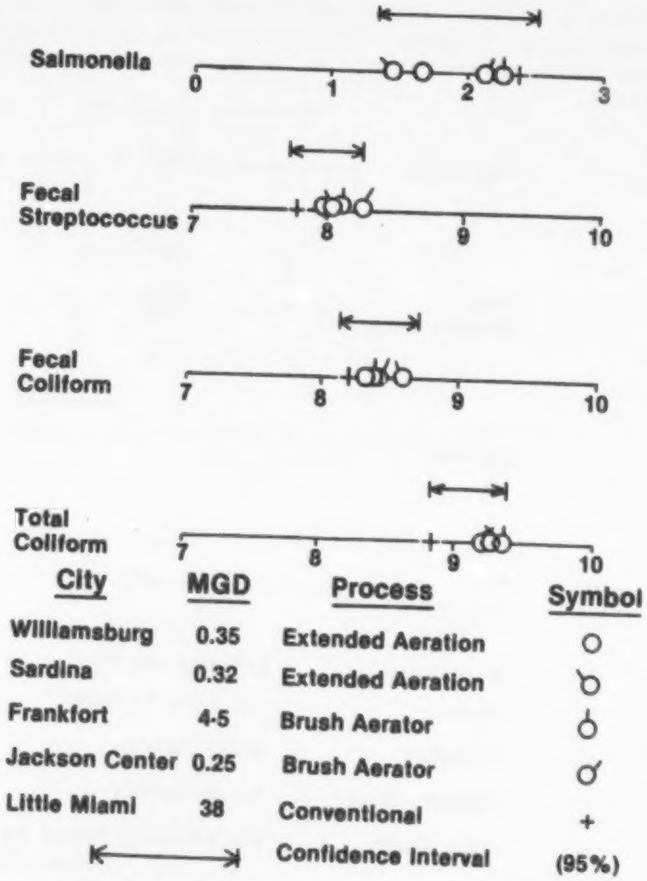


Figure 2. Log of bacterial densities (No./gram) in influent wastewater solids (2).

A recent summary of the available literature and research had identified the kinds and concentrations of pathogenic bacteria, viruses, helminths, protozoans and fungi found in sewage sludges, as well as their fate and transport in the environment and their infectivity to man (3). Table 3 summarizes the survival times for major pathogens of interest. The long survival times (>1 year) for helminths are usually for organisms underground where human exposure and risk are very low. While the Agency has affirmatively evaluated the feasibility of conducting a pathogen risk assessment there are important data gaps to be filled. Among these are control technology issues such as the performance of aerobic digesters. Many of the 3,400 aerobic digesters in the U.S.A. are incapable of meeting the PSRP requirements; particularly during the winter months in the northern States. A research study is currently being conducted at Cornell University on how to upgrade, at minimum cost, the PSRP performance of aerobic digestors through the use of submerged aeration, covers, and insulation.

A feed solids concentration of 2% will be used. A primary research objective is to establish the minimum time requirements (5 to 20 days) to reliably achieve a one-log reduction of pathogens while maintaining an operating temperature of about 30°C. This work is a followup on activity to our earlier research at Cornell on autothermal thermophilic aerobic digestion (ATAD).

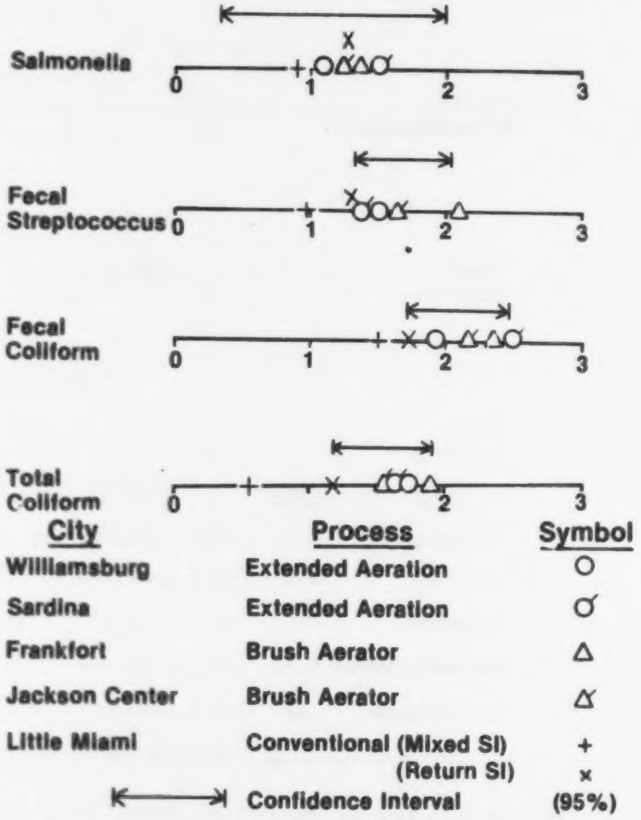


Figure 3. Reductions in log of bacterial densities (No./gram) caused by treatment (2).

TABLE 3. SURVIVAL TIMES OF PATHOGENS ON SOIL AND PLANTS (3)

	SOIL		PLANTS	
PATHOGEN	Absolute Maximum	Common Maximum	Absolute Maximum	Common Maximum
BACTERIA	1 year	2 months	6 months	1 month
VIRUSES	6 months	3 months	2 months	1 month
PROTOZOA	10 days	2 days	5 days	2 days
HELMINTHS	7 years	2 years	5 months	1 month

AUTOTHERMAL THERMOPHILIC AEROBIC DIGESTION

The most extensive study of ATAD in the U.S. was conducted by Jewell (4). This full-scale study, using a 28.4 m^3 (1,000 cu. ft.) reactor, demonstrated that a single-stage digester utilizing self-aspirating aerators with ambient air, treating a continuous feed of primary and waste activated sludge (3%-6% total solids), resulted in autoheated reactor temperatures normally in the range of 50°C to 60°C. Complete inactivation, that is below the limits of detection, of Salmonella and total plaque forming units (viruses) was observed except for one test date. Parasites (viable ova) were reduced significantly, but not completely. Maximum temperature development (55° C to 60° C) and a maximum organic removal rate of 6.5 kg BCOD/m^3-day (.4 lb/day/cu. ft.) occurred when the organic loading rate was 12 to 15 kg TS/m^3-reactor-day (.75 to .94 lb/day/cu. ft.) and the dissolved oxygen concentrations were <1 ppm. Where BCOD is the biodegradable chemical oxygen demand and TS is total solids. Oxygen transfer efficiencies of 20% or more were reported with recommended power input levels of 150 to 200 W/m^3 of reactor. Both a DeLaval Centri-rator aerator and a Midland-Frings aerator were evaluated. Hydraulic retention time varied from 3 to 11 days with 5 days being the most typical value. The dewaterability of the digested sludge deteriorated significantly at all HRT's evaluated.

Even though Jewell's full-scale reactor was not completely mixed as evidenced by stratification of the dissolved oxygen concentration, he described the process performance as being approximately a first-order, completely-mixed steady state system where K, the reaction rate coefficient can be determined by the expression:

$$\frac{SE}{SI} = \frac{1}{1 + K\,(HRT)} \qquad (1)$$

where SE = biodegradable organics out [TVS, gm/l]

SI = biodegradable organics in [TVS, gm/l]

HRT = hydraulic retention time, day

K = reaction rate coefficient, gm biodegradable TVS removed per gm of biodegradable TVS in the reactor per day, day^{-1}

The biodegradable fraction (%) of the sludge constituents was found by Jewell (4) to be as follows:

COMPONENT	BIODEGRADABLE FRACTION (%)
Chemical Oxygen Demand	47.4 - 76.5
Total Solids	22.9 - 62.0
Total Volatile Solids	42.2 - 71.7
Total Kjeldahl Nitrogen	57.0 - 85.0

The reaction rate coefficient K (using COD as a measure of biodegradable organics) is shown in Figure 4 (5). The temperature relationship shown below, which was developed by Jewell (4), is in basic agreement with that of other researchers in the temperature range of 45° to 55°C.

$$K = (0.022)\,1.076^{T_R-20} \qquad (2)$$

where

T_R = temperature of the reactor, °C

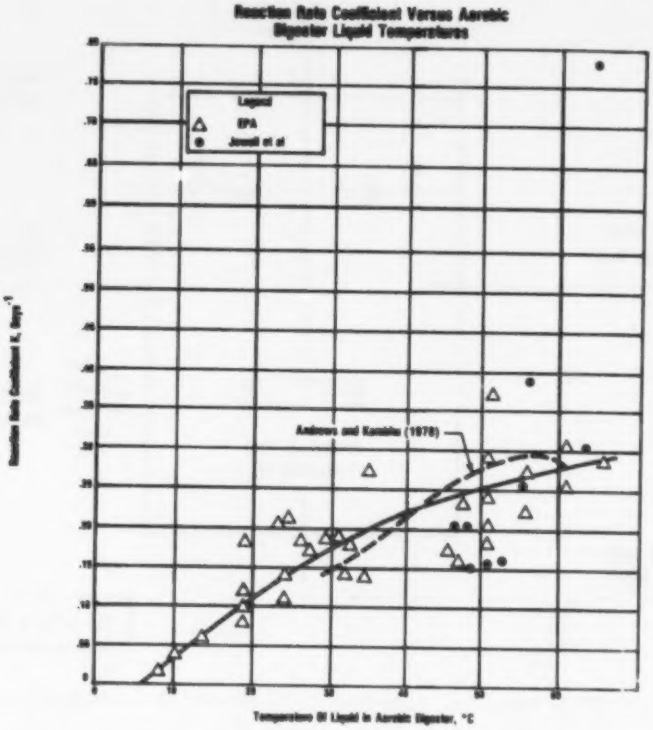


Figure 4. Reaction rate coefficient versus aerobic digester liquid temperatures (5).

Figure 5 illustrates the sources and losses of heat for the aerobic digester. There are three types of heat loss:

- loss through the discharge of exhaust gas
- loss with the digested sludge
- loss to the surroundings.

The first two are the major losses (6). They can be controlled by providing efficient aerators (e.g., 15% efficiency or better) to reduce the flow through the reactor and thickening the sludge fed to the reactor in order to reduce the total quantity of material to be processed. Thickening of sludge to 3% solids or greater has been recommended (5). Convection losses from the reactor can be controlled by covering of the digester and adding insulation.

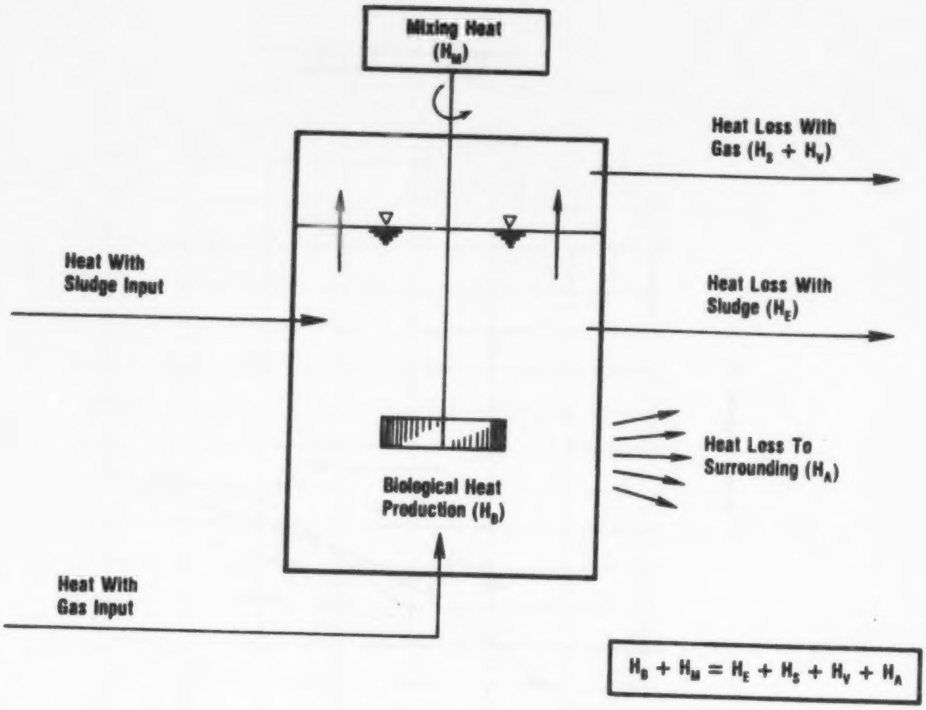

Mixing Heat (H_M)
Heat Loss With Gas ($H_S + H_V$)
Heat With Sludge Input
Heat Loss With Sludge (H_E)
Heat Loss To Surrounding (H_A)
Biological Heat Production (H_B)
Heat With Gas Input
$H_B + H_M = H_E + H_S + H_V + H_A$

Figure 5. Heat balance components for aerobic digestion (5).

Deeny et al, (7) summarized the development of ATAD and described the performance of full-scale facilities in the Federal Republic of Germany (FRG). Aerators utilized by Fuchs (the leading manufacturer of ATAD Systems in FRG) reportedly operated at 95 W/m^3 of reactor volume which is about half of the energy input observed by Jewell. An efficient aeration device is essential if the latent heat loss in the water vapor is to be held to an acceptable level. The largest source of heat is the biological heat production with a typical value of 14,400 kJ/kg (6200 BTU/lb) of oxygen utilized. Carbonaceous oxygen requirements are considered to be 1.42 kg O_2/kg VSS oxidized. Biological nitrification is precluded at thermophilic temperatures which substantially reduces the oxygen demand compared to conventional aerobic systems.

Figure 6 from Deeny et al, (7) illustrates the substantial capital cost savings associated with the ATAD technology compared to conventional aerobic and anaerobic digestion for small to medium sized facilities. These costs (U.S. dollars - March 1984) include the prethickening to 3 - 5 % TS, the ATAD system with 6 days HRT, post-treatment storage for 20 days, pumping system and concrete slab. Operating costs for ATAD technology were estimated (5) to be lower than aerobic digestion at all plant sizes (3,800 m^3/d to 380,000 m^3/d) but higher than anaerobic digestion for plants with a capacity of 38,000 m^3/d (10 MGD) and larger. The technology was relatively easy to operate with several systems reporting that less than one hour

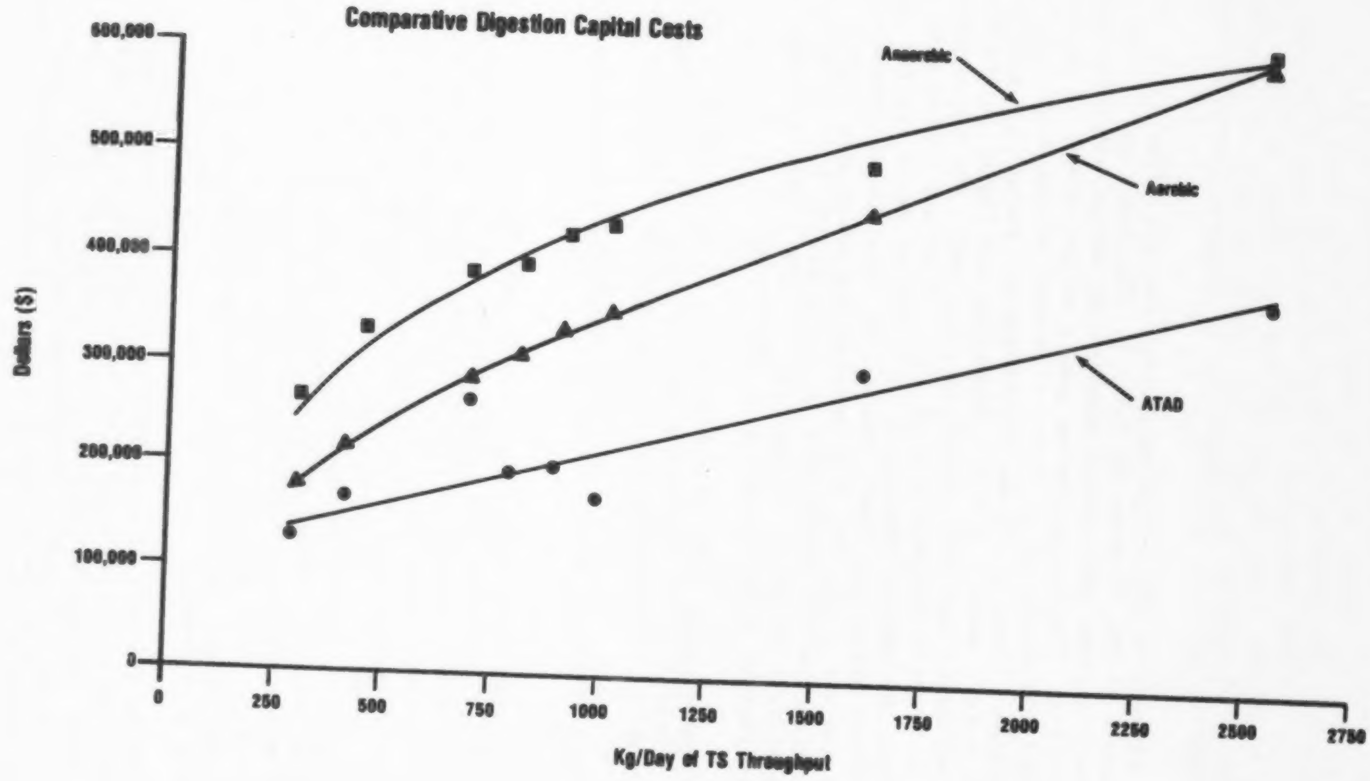


Figure 6. Comparative digestion capital costs (7).

per day was required to operate and maintain the system. Performance was very acceptable including: 40% reduction of volatile solids, thermophilic (>43°C) temperature operation in the second stage reactor, apparent pathogen reduction to the FRG limitation of 100 enterobacteria/ml and infrequent incidence of odors. The ATAD process has been shown by Strauch and Bohm to be capable of destroying salmonella, parasite eggs and viruses provided a temperature of 50°C is maintained for 57 hours of aeration time (6).

A summary of the design parameters for all three of the ATAD manufacturers in FRG is shown in Table 4. The Fuchs and Thieme systems employ two insulated and covered reactors in series operation with batch feeding cycles. The Thieme system uses a rotary screen to prethicken the sludge feed concentration to 10 to 12 percent solids which results in a 70% reduction in reactor volume requirements. Fuchs also prethickens the sludge to 3 to 5 percent solids. Dissolved air flotation thickening of primary and waste activated sludge is practiced. The batch feeding cycle is used to prevent contamination of the pasteurized sludge with incoming raw sludge. Mechanical components in a typical Fuchs reactor consists of two rotary blade type foam cutters, two side mounted aspirator type aerators and one center floating aerator depending upon reactor sizing. Design oxygen transfer efficiency is 2.1 kg O_2/kWh (3.5 lb O_2/hp-hr). A 20-day storage period is recommended for the digested sludge to cool (20°C) to improve post thickening or dewatering.

Figure 7 shows the schematics for all three systems. The Babcock ATAD system utilizes a single reactor with semi- or fully-continuous sludge feeding. A submerged turbine is used for aeration in this system.

Actual operating conditions for five Fuchs systems is shown in Table 5 (7).

The ATAD batch operating strategy maximizes pathogen destruction potential and minimizes the possibility of product contamination from incoming sludge. A specific volume is removed daily from the second stage reactor. A comparable volume is then transferred daily from the first stage to the second stage which provides a minimum detention time of 24 hours at thermophilic temperatures. Some researchers have been concerned about possible temperature depression in the first stage with a batch feeding operation . Deeny et al, (7) observed that the first and second stage temperatures were depressed by approximately 5 to 6°C and 3 to 4°C, respectively. Both reactors recovered at a rate of 1° per hour. Volatile solids destruction were reported as being >40 percent at detention times in excess of 4 days.

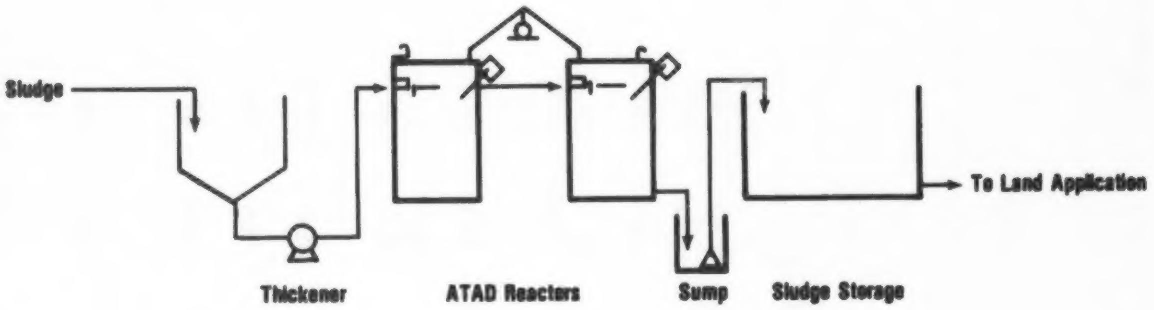
There are only limited data on sludge dewatering performance. Experience at the Vilsbiburg ATAD facility using a belt press and decanter centrifuges indicate acceptable performance with sludge cake total solids of 30 to 35 percent with a feed solids content of 2.5 percent (7). Polymer dose was approximately 5 g/kg of sludge. Feed temperature range was 48 to 63°C.

TABLE 4. SUMMARY OF ATAD DESIGN PARAMETERS (7).

DESIGN PARAMETER	MANUFACTURERS		
	FUCHS	THIEME	BABCOCK
Sludge Feed Concentration, percent (%)	3-5	10-12	3-6
Hydraulic Detention Time, Days	5-6	6-7	3-6
Number of Reactors	2	2	1
Sludge Storage Capacity, Days	20	70	-
Operating Strategy	Batch	Batch	Semi-Continuous
Aeration Requirement, KWH/M^3 of sludge throughput	12-14	-	12-17
Mixing Requirements, W/M^3 reacter volume	86	200-300	-

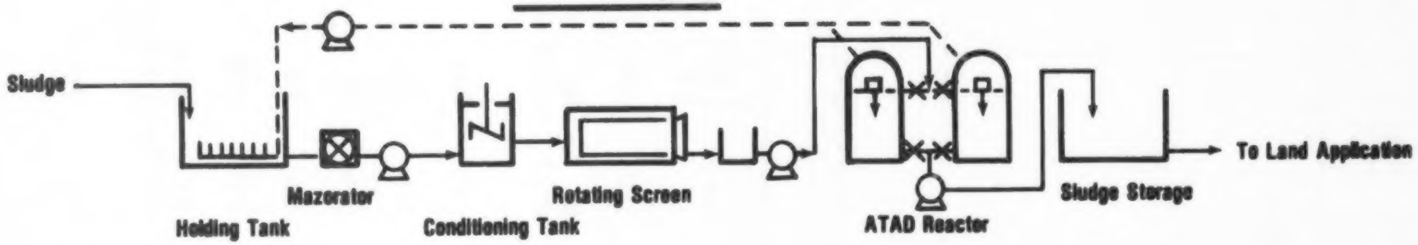
TABLE 5. SUMMARY OF ATAD ACTUAL OPERATING CONDITIONS

Parameter	Facility				
No. of Reactors	2	2	2	2	2
Dimension, ØxH, M	5 x 3	7.0x 3.5	7.5x4	3.5x 2.5	6.5x 2.25
Volume (Occupied by Sludge) Total, m^3	120	120	360	48	150
Sludge Influent Flow, m^3/day	9	20	70	8	15
Sludge Concentration, TSS/TVSS, percent	4/3.1	4/3.4	5.5/ 3.6	5/3.0	3.5/ 2.8
Sludge Mass Loading, TVSS, kg/day	280	680	2,520	240	420
Sludge Volumetric Loading, kg/day/m^3	2.3	5.7	7.0	5.0	2.8
Reactor(s) Detention Time, days	13 (6.6)	12 (6)	5.1	6.0	10
Aeration Installed Power, kw	8.8	9.5	38	4.4	11.8
Aeration Power Consumption , kwh	211	228	912	106	284
Aeration Power/ Sludge Volume, kwh/m^3/day	23.4 (12.0)	22.8 (12.6)	13.0	13.3	18.9
Aeration Power/ Reactor Volume, w/m^3	73	79	106	92	79
Aeration Power/ Sludge Mass, TVSS, kwh/kg/day	0.75	0.74	0.36	0.44	0.68



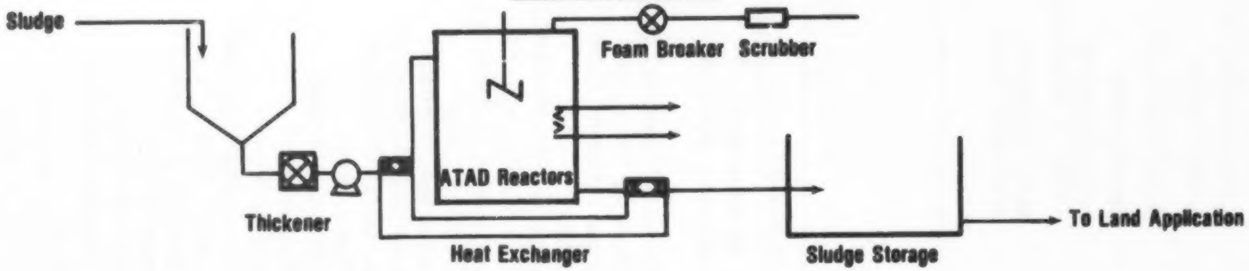
Sludge
To Land Application
Thickener
ATAD Reactors
Sump
Sludge Storage

Fuchs ATAD System



Sludge
To Land Application
Mazorator
Holding Tank
Conditioning Tank
Rotating Screen
ATAD Reactor
Sludge Storage

Thieme ATAD System



Sludge
Foam Breaker
Scrubber
ATAD Reactors
Thickener
Heat Exchanger
Sludge Storage
To Land Application

Babock ATAD System

Figure 7. Alternative flow schemes of ATAD systems.

APPLICATION OF ULTRAVIOLET LIGHT FOR DISINFECTING WASTEWATER

The use of Ultraviolet Radiation (UV) for the disinfection of treated domestic wastewaters has evolved relatively quickly from the development and demonstration stages to full scale application. This has been spurred in large part by the U.S. Environmental Protection Agency's (EPA) direct research funding efforts and its encouragement to build UV plants through its Construction Grants Innovative and Alternative (I/A) Program. Over the last 10 years the technology has received considerable attention, with an increasing number of full-scale plants coming on line, particularly over the last three to five years. UV disinfection is being considered at approximately 120 municipal wastewater facilities in the U.S.A. Currently some 60 are in operation with the remainder under design or construction. Most of these facilities are quite small. The largest facility at, Madison, Wisconsin, will have design flow of 2.4 m^3/s (55 MGD). The process application is viable, technically feasible, and cost-effective for most wastewater situations.

A comparison of costs had been performed in 1979 as part of an evaluation of UV disinfection at Northwest Bergen County, New Jersey. This study had assembled unit costs for a number of disinfection processes and compared them to the estimated unit cost for UV disinfection. These same unit costs are presented on Figure 8, updated to 1984 (USEPA Index = 460). Unit costs developed from a recent study (8) of existing full-scale UV disinfection facilities have also been included in Figure 8. In certain cases, a wide range in cost estimates was found for a specific process. The values used on Figure 8 represent an approximate average of the various estimates to achieve an effluent quality objective of 200 FC/100 ml. Additionally, the costs presented in various sources may differ in their assumptions for labor, power, etc. Caution is, therefore, warranted in any direct cost comparisons.

The analysis presented on Figure 8 suggests that UV is considerably less expensive than ozonation and is competitive, if not less expensive, than the chlorination or chlorination/dechlorination processes. It was found that the costs estimated for UV in our recent study (8) were less than the estimates from the 1979 report. The reasons for this are primarily the reduction in real costs for equipment and the more rational manner in which UV systems can now be designed. A noted shortcoming in the application of UV, however, has been the lack of a generic, technically acceptable design approach. Most in-field designs, with a few notable exceptions, have relied on equipment manufacturers for system sizing and hardware designs. These have been based on limited experience with wastewater applications and have often followed generalized rules of thumb. The design assumptions and the hardware configurations themselves often do not adequately account for the basic variables that are key to effective UV design and performance.

The most common configurations are the "submerged" quartz covered lamp designs of Pure Water Systems, Inc. and Ultraviolet Purification Systems, Inc. and the teflon tube flow-through design of ENERCO.

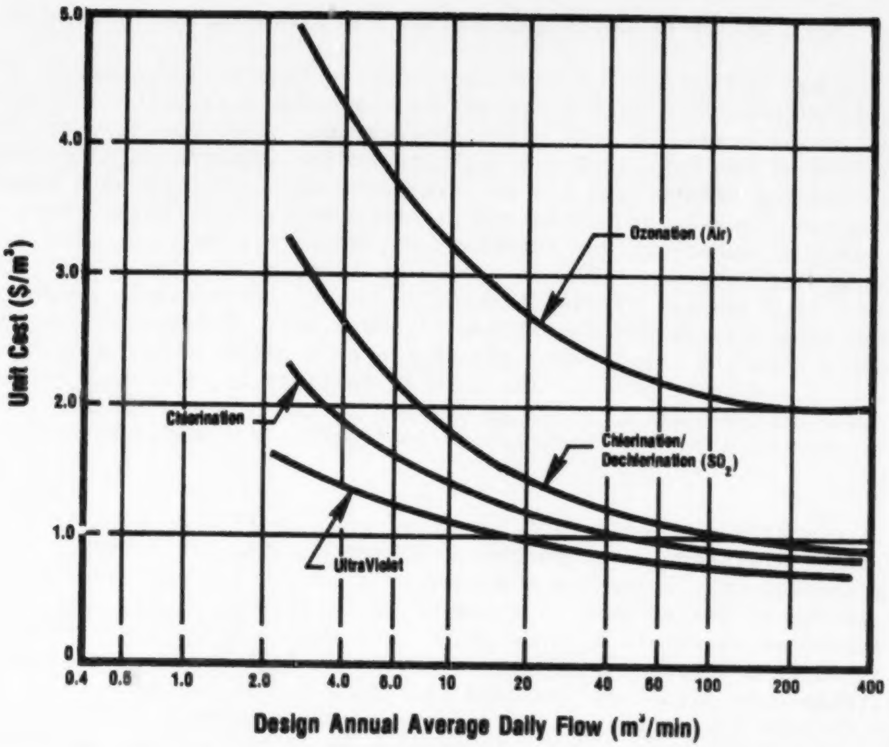


Figure 8. Comparison of unit costs for alternative disinfection processes (9).

A systems analysis procedure has been developed as part of a recently completed EPA study at the Port Richmond Water Pollution Control Plant in New York City, and reported by Scheible, et al. (9). The procedure incorporates the use of mathematical modeling techniques, which generically describe the hydraulic, kinetic, and water quality elements important to UV disinfection. The utility of the modeling approach, when properly applied, is the efficient evaluation and optimization of an existing system, and the optimization of a design for a new system.

The following discussion presents the application of this procedure to a full-scale system. The tasks associated with this study involved collecting the appropriate data to calibrate the disinfection model, and then using the model to evaluate the system design, particularly under anticipated design loading conditions. The objectives were to assess the utility of the procedure and to determine what modifications and/or refinements would be appropriate to strengthen it. A brief discussion of the model is first presented; this is followed by a discussion of the key elements of the model and how these were determined for the study site. The use of the calibrated model is then presented, with a discussion of observations and conclusions derived from the study.

UV DISINFECTION MODEL

The reader is referred to the Port Richmond study report (9) for a detailed development of the disinfection model. It incorporates an estimate of the residence time distribution in the reactor, describes the inactivation rate as a function of the intensity, and empirically accounts for the effect of particulates on UV performance efficiency. The expression is written:

$$N = N_o \exp \left[\frac{ux}{2E}\left\{1 - \left(1 + \frac{4EK}{u^2}\right)^{1/2}\right\}\right] + N_p \qquad (3)$$

where:

N = the bacterial density remaining after exposure to UV (organisms/100 ml)

N_o = the initial density, measured immediately before entry into the UV reactor (organisms/100 ml)

x = the distance traveled by an element of water while under direct exposure to UV light (cm). This is generally taken as the reactor dimension in the direction of flow.

u = the velocity of the wastewater as it travels through the UV reactor (cm/sec). This is calculated as:

$$u = x/V_v/Q)$$

where Q is the flow rate in liters/second and V_v is the reactor liquid volume in liters.

E = the reactor dispersion coefficient in cm^2/sec.

K = the inactivation rate coefficient ($second^{-1}$).

N_p = the bacterial density associated with the particulates in the wastewater. These coliforms are affected minimally by the UV radiation, effectively becoming the base residual density determining the performance of a given system.

Thus, the information required by the model includes the dimensions of the reactor (x, V_v), and the system loading conditions (Q and N_o); E describes the hydraulic characteristics of the unit. The sensitivity of the coliforms is described by the inactivation rate, K; this, in turn, is estimated as a function of the calculated intensity. The wastewater characteristics are described by the K rate, the particulate coliform density, N_p, and by the UV absorbance coefficient.

DETERMINING THE MODEL PARAMETERS FOR EXISTING FULL-SCALE SYSTEMS

The following discussion briefly describes the approach and data requirements for properly calibrating the model. From the above presentation, this can be addressed by evaluating three basic elements:

1. hydraulic characteristics,
2. intensity of UV in the UV reactor, and
3. water quality conditions for the wastewater.

Hydraulic Characteristics

The data requirement for determining the appropriate hydraulic characteristic of the UV reactor lies principally in determining its residence time distribution (RTD). Hydraulically, the design objectives are to have a reactor that behaves in a plug flow manner with minimal dispersion; that the flow be turbulent radially from the direction of flow; and that the reactor liquid volume be used effectively.

Figure 9 from (10) present a "typical" RTD curve, which can be developed by injecting a conservative tracer into the influent of a reactor and measuring its concentration, c, as it exits the reactor with time. Several indices can be estimated from the RTD curve that are useful in describing the hydraulic behavior of the reactor. Referring to Figure 9, these are defined as follows:

t_{90}/t_{10} = the ratio of the time for 90% of the tracer to pass to the time for 10 percent of the tracer to pass. This is commonly known as the Morrill Dispersion Index; it would be equal to 1.0 for ideal plug flow conditions, and 21.9 for complete mix. Generally, it is best to have this index less than 2.

t_m/T = the ratio of the actual mean residence time (first moment of the RTD curve) to the theoretical residence time. T is computed as the liquid volume, V_v, divided by the flow rate, Q.

t_p/T = the ratio of the time at which the peak concentration occurs to the theoretical residence time.

t_f/T = the ratio of the time when tracer first appears to the theoretical residence time.

t_{50}/t_m = the ratio of the time for 50% of the tracer to pass to the mean residence time. The deviation from a value of one is a measure of skew from a normal distribution. As an example, a value significantly less than one would characterize an RTD with a long tailing effect, indicative of stagnant areas within the reactor.

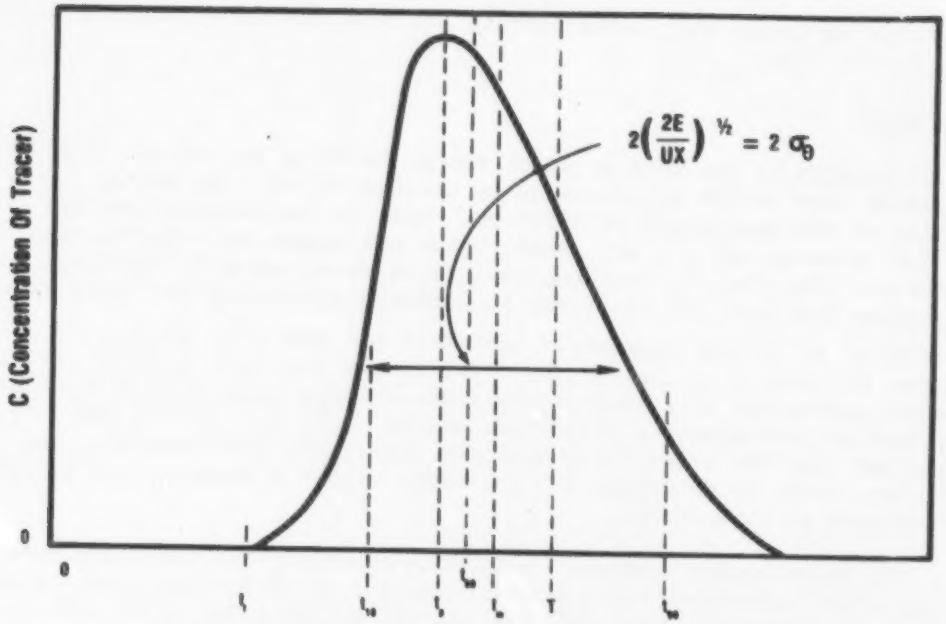


Figure 9. Typical residence time distribution curve (10).

A very useful parameter, particularly in reactor design, is the dispersion number:

Dispersion Number = E/ux

where E is the dispersion coefficient (cm^2/second), u is the fluid velocity, and x is the reactor dimension in the direction of the flow. The dispersive properties of a reactor are indicated by the relative spread of the RTD curve. The value of E will approach infinity in completely mixed systems, while in ideal plug flow systems it will approach zero. Levenspiel (11) suggests values of the dispersion number for a plug flow reactor with increasing degrees of dispersion:

E/ux = 0; plug flow, no dispersion

= < 0.01; low dispersion

= 0.01 to 0.1, moderate dispersion

= > 0.1 high dispersion

In cases where the RTD is a normal (Gaussian) distribution, the dispersion number can be estimated from the variance of the distribution:

$$\sigma_\theta 2 = \frac{\sigma^2}{t_m^2} \sim 2\left(\frac{E}{ux}\right) \tag{4}$$

where the variance, σ_θ^2, normalized to the mean residence time, is dimensionless.

Intensity

Intensity is the rate at which energy is being delivered. The unit generally used for UV disinfection is microwatts/cm^2; the energy is specifically at the wavelength of 253.7 nm. This is the maximum spectral line for low pressure mercury arc lamps, which are almost universally used in wastewater disinfection systems. A serious shortcoming in the design of UV systems has been the inability to estimate accurately the light intensity in complex multi-lamp reactors. Detectors are generally planar and will account for only a portion of the light energy available within a system. Several approaches have been proposed to estimate light intensity, including chemical actinometry, biological assays (12), and calculation. It is suggested that the calculation approach offers the most versatile and efficient means to determine the intensity within a reactor, and is the method used in this study.

The point source summation method is generally the technique used to calculate intensity. It was first applied to UV disinfection systems by Johnson and Qualls (12) and then applied by Scheible, et al (9). It presumes that the lamp is a finite series of point sources, each of which radiates its energy radially. The energy attenuates by two mechanisms: the first is by dissipation and is proportional to the inverse of the radius squared; the second is by absorption by the medium through which the energy is passing.

A single receptor in the reactor will be exposed to all point sources that have an unobstructed straight line path to the receptor. The intensity, therefore is the sum of the intensities from all point sources affecting the receptor. This calculation is then performed for a number of receptors located in a defined cross-sectional grid pattern, allowing one to eventually compute the average intensity in the reactor. The final product is generally a plot of the average nominal intensity as a function of the wastewater UV absorbance coefficient.

The reader should refer to the cited references for a more detailed discussion of the calculation technique. The information required to compute the intensity for a given system may be summarized as follows:

- reactor dimensions and the configuration of the lamps and lamp enclosures

- the output rating of the lamp. The nominal rating for low pressure mercury arc lamps is approximately 18.2 Watts/meter of arc (at 253.7 nm). This will degrade with use; thus it is also important to understand the lamp output with time.

- the absorbance of the liquid to be treated. This is the absorbance coefficient at 253.7 nm (base e), with the units cm^{-1}.

- the transmissibility of the enclosures; submerged lamp systems have quartz sheaths about each lamp. Other systems utilize Teflon tubes to carry the liquid, with the lamps surrounding the tubes. In either case, the energy must pass through the enclosure before it reaches the liquid. Thus, it is important to account for the loss of energy through these enclosures.

In the example that is to be provided, the intensity calculation is made assuming that all the lamps are at their nominal output rating and that the enclosures will transmit 100 percent of the energy. This allows general use of the calculation output; the resulting intensity need only be adjusted (by direct ratio to nominal) for actual and/or projected conditions.

Wastewater Quality

The four wastewater parameters that most affect the design or performance of a UV system are the flow, initial bacterial density, suspended solids (or some measure of the particulates in the wastewater), and the UV absorbance of the wastewater. The flow rate is set by the design of the main plant and projected hydraulic loads from the facility collection system. The initial density is a parameter that is not generally monitored at a facility; in the case of disinfection by UV, however, it is a critical parameter.

The occlusion of bacteria in particulates will have a significant effect on the design of a system. For model calibration and system evaluations it is best to use the suspended solids analysis as the primary indicator of particulates. The level of suspended solids in the effluent of a wastewater treatment plant is, in effect, set by the design of the plant, limiting the range of suspended solids concentrations to be considered in the design of the UV process.

The one parameter that is solely in the venue of UV disinfection is the UV "demand" of the wastewater, in which components in the water will absorb energy at the 253.7 nm wavelength. The spectrophotometric UV absorbance coefficient is a measure of the UV "demand" of the water and is used in the context of the model expression (and intensity calculations), with the units cm^{-1}.

The single beam spectrophotometric method for measuring absorbance is the simplest procedure. This "direct" method, however, does not account for light which is scattered and still available; the detector does not receive this light and thus considers it to be absorbed. Integrating sphere accessories are available to correct the absorbance reading for this effect and give a more representative measure of the true absorbance. If such an instrument is not available, a direct measurement of the sample filtrate would give a reasonable approximation of the true absorbance.

Calibrating the Model

Referring to Equation 3, for a fixed, existing system, we are given the variables of flow, the dimension x, the velocity u; from the water quality data we can estimate the initial density, N_o. The task of calibrating the model, for an existing system, then involves determining the dispersion coefficient E, the inactivation rate K, and the density associated with the particulates, N_p.

Dispersion Coefficients. As discussed above, the dispersion coefficient can be estimated from the RTD curve developed from direct tracer analyses of the reactor. If the distribution is approximately normal, E can be estimated from Equation 4. Alternatively, the E can be estimated from a series of trial and error solutions to the following equation:

$$\frac{dc}{dt} = \frac{W}{2A(\pi Et)^{1/2}} \exp \left[\frac{-(x - ut)^2}{4Et}\right] \qquad (5)$$

where:

$\frac{dc}{dt}$ = observed change in concentration of tracer with time (gm/l/sec)
W = rate of mass input (gm/sec)
A = cross-sectional area of the tracer stream at x (cm^2)
x = distance from injection to the observation point (cm)
u = velocity (cm/sec)
t = time (sec)
E = dispersion coefficient (cm^2/sec)

Estimate of the Coliform Density Associated with Particulates

The data required to estimate these densities are collected from the UV system at very high apparent dose levels. This can be done by operating the full system at low flow rates. The premise is that the remaining densities measured after such high doses are those that are associated with the particulates and would not have been affected by the UV radiation. These data are then correlated with the suspended solids of the sample (or some other measure of particulates, such as turbidity).

A linear regression analysis can be performed of the log effluent fecal coliforms as a function of the log effluent suspended solids. When transformed this will yield an expression in the form,

$$N_p = cSS^d \qquad (6)$$

where N_p is the density associated with the suspended solids (organisms/100 ml) and SS is the suspended solids concentration (mg/l). The coefficients c and d are the intercept and slope of the regression line, respectively. The coefficients c and d at Port Richmond were 0.25 and 2.0, respectively.

Estimate of the Fecal Coliform Inactivation Rate. The required data are those in which the operating conditions would allow a still significant coliform density in the effluent. This permits one to use the influent and effluent coliform densities to estimate the rate of inactivation. These data are generally collected under high hydraulic loading conditions.

Once the data are collected, the rate can be estimated for each sampling by manipulation of the model expression (Equation 3) to solve for K. The estimate of N_p is first made (as discussed earlier) and subtracted from the measured effluent density:

$$N' = N - N_p \qquad (7)$$

Manipulation of Equation 3 yields:

$$K = [u^2(P^2 - 1)]/4E \qquad (8)$$

where:

$$P = 1 - \left[\frac{2E \ln (N'/N_o)}{ux}\right] \qquad (9)$$

The log K can be regressed against the log intensity for the corresponding sampling. This would yield the expression (when transformed) in the form:

$$K = a\ I_{avg}^{\ b}$$

where K is the inactivation rate in seconds^{-1}, and I_{avg} is the average intensity (uWatts/cm^2). The coefficients a and b are the intercept and the slope of the regression line, respectively.

In summary, the final calibrated model will take on the form:

$$N = N_o \exp \left\{\frac{ux}{2E}\left[1 - \left(1 + \frac{4E\ aI_{avg}^{\ b}}{u^2}\right)^{1/2}\right]\right\} + cSS^d \qquad (10)$$

SITE EVALUATION AT SUFFERN, NEW YORK

A full-scale, operating UV system was evaluated as part of this special study project. Recall that the intent was to collect the appropriate information about the system's hydraulics, performance, and the wastewater characteristics. These would be used to calibrate the disinfection model, which in turn would be used to evaluate the system design. Secondarily, an objective was to evaluate the model analysis procedure itself, and to determine refinements and/or modifications necessary to enhance its utility.

Methods

Analytical methods for fecal coliforms, chemical oxygen demand (COD), suspended solids (SS), and turbidity followed Standard Methods (13) and USEPA (14) procedures. The UV absorbance coefficient was measured at 253.7 nm with a Perkin-Elmer 552A-UV Visible Scanning Spectrophotometer. The correction for scattering in the UV absorbance measurement (spherical absorbance coefficient) was accomplished with a necessary Integrating Sphere (Model No. B010-3751). The materials and methods for measuring the residence time distribution of the UV reactors, and the output and transmittance of the UV radiation were described elsewhere (8,9).

Process Description. The UV process at Suffern consists of two parallel units, designated as Units 1 and 2, both designed for 10,600 lpm (4.0 mgd) maximum flow. The average design flow is 5,000 lpm (1.9 mgd). The units are submerged quartz systems with the flow directed perpendicular to the lamps. Upon entering the influent chamber the water must pass through an inlet stilling plate prior to contact with the UV light. A similar plate exists at the exit from the lamp pattern. These were installed to ensure uniform flow distribution through the unit. Each unit has 260 lamps arranged in a staggered pattern with the length having a total of 35 lamps and the height alternating between 7 and 8 lamps. The units can be operated with one to four banks of lamps on.

Systems Hydraulics. Several tracer measurements were made at Suffern to determine the hydraulic characteristics of the units.

From an analysis of the mean and variance of the distribution, the dispersion number is estimated to be 0.037. This suggested a low to moderately dispersive plug flow reactor. The hydraulic indices can also be calculated, and are summarized on Table 6. These suggest that there is a degree of axial mixing occurring in the reactor. This is supported by the low value of t_f/T, and the dispersion numbers. The lower value of t_p/T suggests that the total void volume is not being used effectively. These data and those from the other tracer runs indicated that an effective volume of 70 percent actual should be used in subsequent analyses.

TABLE 6. SUMMARY OF HYDRAULICS ANALYSIS, SUFFERN, N.Y.

Parameter	Measured Value
Dispersion Coefficient, E, cm^2/s	150
Dispersion Number, d	0.037
t_f/T	0.35
t_p/T	0.83
t_{90}/t_{10}	2.2
t_m/T	0.88
t_{50}/t_m	1.04
Estimated Effective Volume (% of Actual)	70

Intensity Calculation. The cross-sectional dimensions of the lamps and quartz sleeves are given on Figure 10, which also presents an example of the intensity field calculated for an absorbance coefficient of 0.2 cm^{-1}. The average intensity is reduced from this type of intensity field analysis.

The final product of these calculations is presented on Figure 11. As already discussed, these estimates must then be adjusted for the actual lamp output and the estimated quartz transmissibility at the time of sampling. Direct measurements were made at Suffern. The lamp outputs were found to average 95 percent of their nominal rating (the plant was in startup); the quartz transmittance was determined to range from an average of 60 to 40 percent (relative to a clean quartz sleeve) during the term of the study. These were applied to the intensity estimates for each sampling. The data are summarized on Table 7.

Estimation of the coefficients c and d. Insufficient data were generated at Suffern to give an accurate estimate of the coefficients c and d. It was presumed, therefore, that the values derived for the coefficients in the Port Richmond project would give a reasonable approximation of the fecal coliform density associated with the effluent suspended solids.

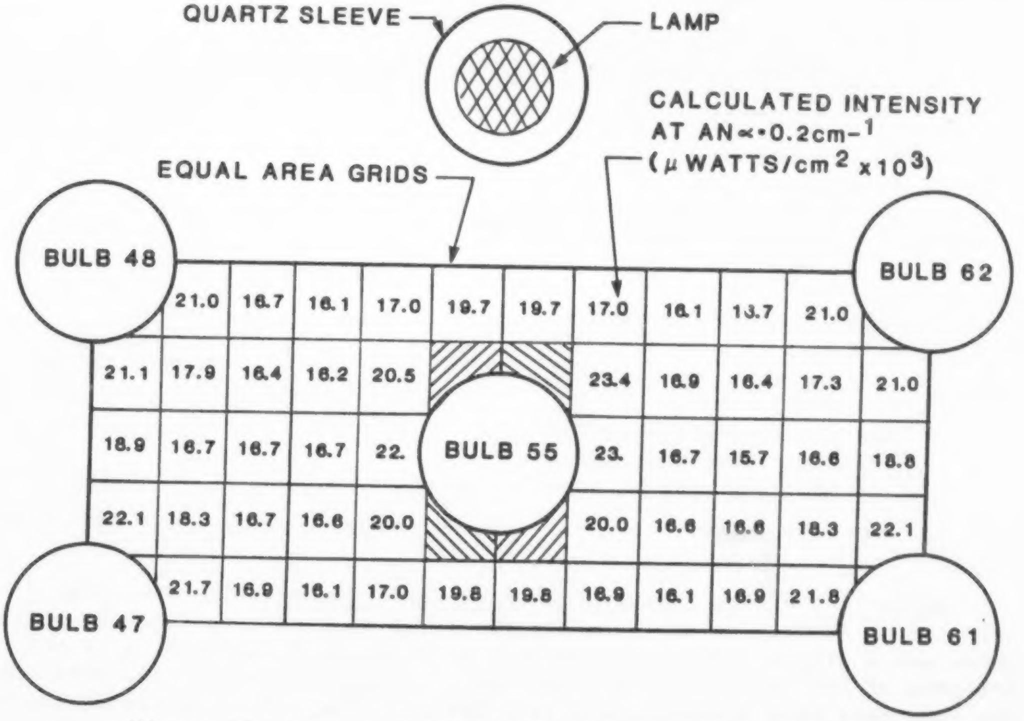

QUARTZ SLEEVE
LAMP
CALCULATED INTENSITY
AT AN∝·0.2cm^{-1}
(μWATTS/cm^2 x10^3)
EQUAL AREA GRIDS
BULB 48
BULB 62
BULB 55
BULB 47
BULB 61
21.0 16.7 16.1 17.0 19.7 19.7 17.0 16.1 13.7 21.0
21.1 17.9 16.4 16.2 20.5 23.4 16.9 16.4 17.3 21.0
18.9 16.7 16.7 16.7 22. 23. 16.7 15.7 16.6 18.8
22.1 18.3 16.7 16.6 20.0 20.0 16.6 16.6 18.3 22.1
21.7 16.9 16.1 17.0 19.8 19.8 16.9 16.1 16.9 21.8

Figure 10. Cross sectional dimensions of lamps/quartz in Suffern unit, with an example of a calculated intensity profile in one area (9).

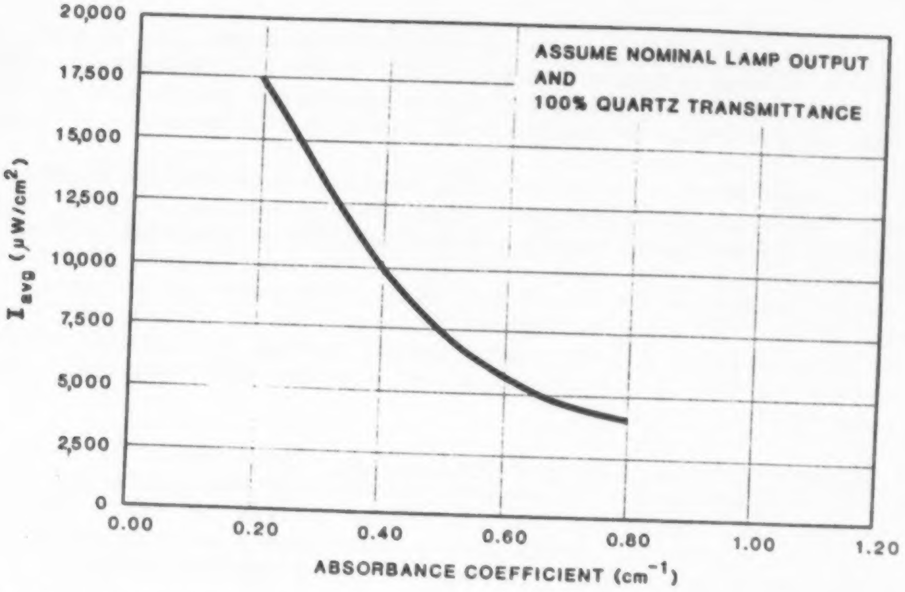


Figure 11. Calculated average intensity vs. UV absorbance coefficient (10).

TABLE 7. SUMMARY OF FIELD DATA FROM SUFFERN, N.Y.

Parameter	Measured Value
No. of Samplings	64
Flow Range, l/s	52 - 138
N_o, fecal coliforms/100 mL	
(Geometric Mean)	95,500
(Range)	20,000 - 274,000
UV absorbance coefficient, cm^{-1} (base e)	
(avg)	0.282
(range)	0.235 - 0.350
Nominal Intensity, μW/cm^2	13,880
Adjusted Intensity, μW/cm^2 (95% lamp output, 40-60% transmittance)	6,600

Estimation of the Inactivation Rate Coefficients. The samplings selected at Suffern to estimate the inactivation rate were those in which there was a single bank operating at a high flow. A shortcoming in the analysis of the data at Suffern is that the range of intensities over which the rate data were collected was very narrow. The system configuration at Suffern did not allow for artificial adjustments to the unit intensity (such as reducing the line voltage, etc.); the variation would only be induced by the changes naturally occurring in the UV absorbance of the wastewater.

The estimates of K were regressed as a function of the estimated average intensity. The effective volume that was used to estimate the velocity in Equation 10 was assumed to be 70 percent of the actual liquid volume; this was based on the hydraulics analysis discussed earlier. The transformed regression line from the log-log plot of the Suffern data is written:

$$K = 0.00059\ I_{avg}^{0.922}$$

Model Calibration. The calibration of the Suffern wastewater to the model (Equation 10) uses the following coefficient values:

$a = 0.00059$
$b = 0.922$
$c = 0.25$
$d = 2.0$

The dispersion coefficient E was assumed to be 150 cm^2/second. Figure 12 presents a comparison of the observed data to the predicted data for effluent fecal coliforms. As can be seen, the model was very effective in predicting the performance of the system and responding correctly to the

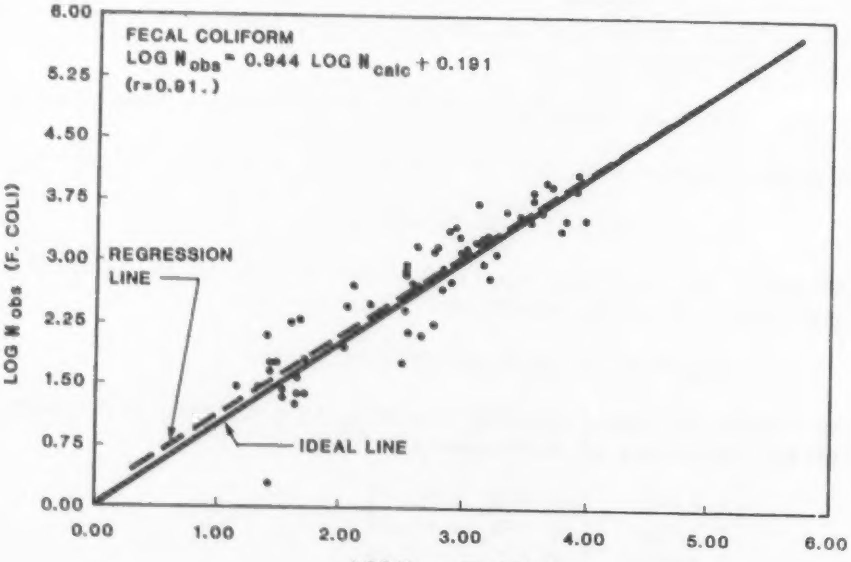


Figure 12. Comparison of observed densities to calculated densities [Suffern] (10).

parameters that defined the process operations. Ideally, the slope of the regression line for the correlation of the observed and predicted data should equal 1.0, with an intercept of zero. Analysis indicated that in either instance the regression line was not significantly different (0.05 level) from the ideal line.

Analysis of the Suffern UV System

Figure 13 presents solutions to the calibrated model expression in situations where there are 1, 2, 3, and 4 banks of lamps in operation. The Suffern plant is designed to handle an average flow of 5,000 lpm (1.9 mgd) and a peak daily flow of 10,600 lpm (4.0 mgd). The treatment requirements at the plant call for seasonable nitrification and disinfection (April through October). The two units at Suffern are each designed to handle the total plant flow, even during peak conditions.

Let us first consider the system under average loading conditions:

Average UV absorbance Coefficient = 0.3 cm^{-1}
Average Suspended Solids = 15 mg/l

Average daily flow = 5,000 lpm (1.9 mgd)

Average Initial Fecal Coliform Density = 120,000/100 ml

Assume that the average output of the lamps is approximately 80 percent nominal and that the quartz transmittance is maintained at a level no less than 60 percent. Referring to Figure 11, the calculated intensity is 13,500 μWatts/cm^2 at an absorbance coefficient of 0.3 cm^{-1}. This is then adjusted:

Average Intensity = 13,500 x 0.8 x 0.6 = 6480 μWatts/cm^2

The density associated with the suspended solids is estimated:

$$N_p = 0.25(15)^2 = 56 \text{ FC/100 mL}$$

Assuming a mean effluent density of 200 FC/100 mL is required, the N' is equal to 200 - 56 = 144 FC/100 mL. This yields,

$$\text{Log } N'/N_o = \text{Log } (144/120000) = -2.92$$

From Figure 13, the following Log N/N_o is predicted at average flow and at an average intensity of approximately 6500 μWatts/cm^2:

1 Bank, Log N/N_o = -1.75
2 Banks, Log N/N_o = -3.40
3 Banks, Log N/N_o = -5.00
4 Banks, Log N/N_o = -6.80

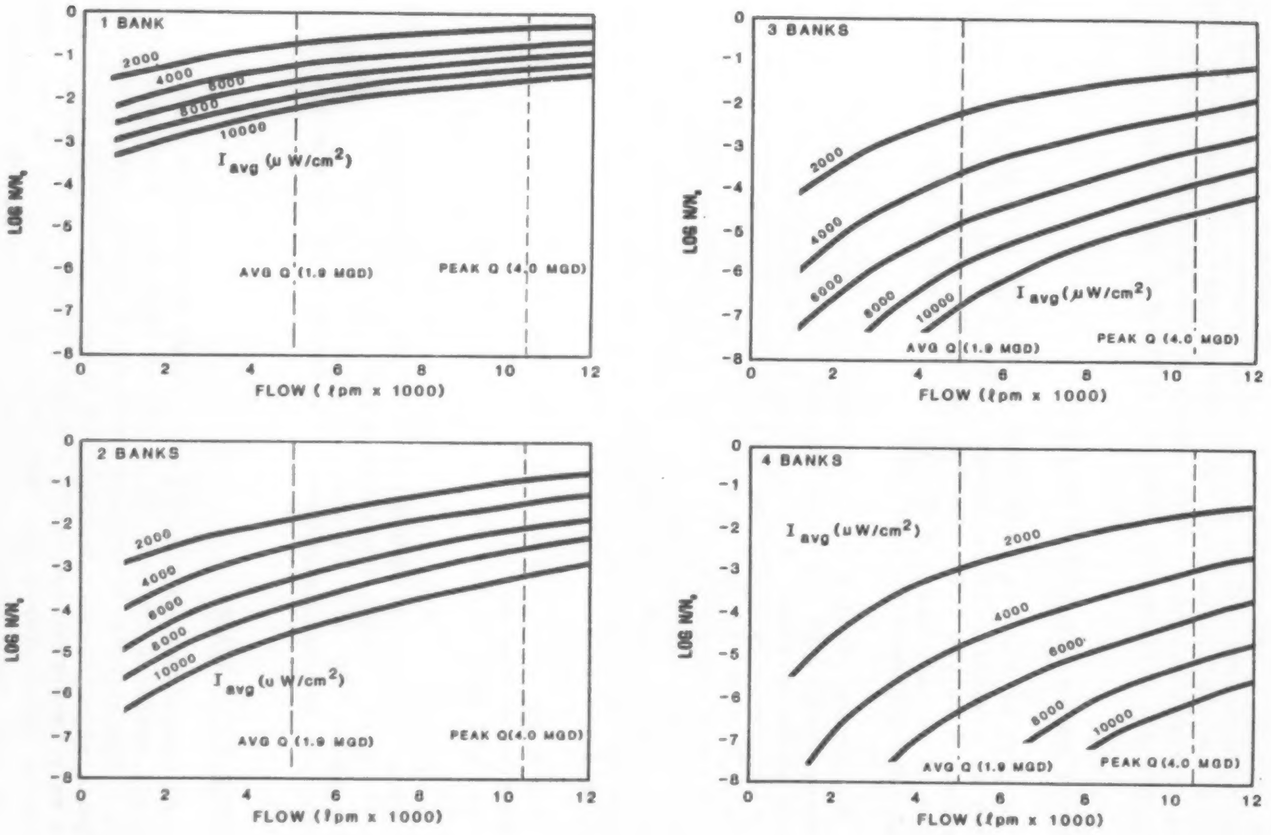


Figure 13. Model solutions for the Suffern UV system [fecal coliform] (10).

This analysis suggests that under average conditions, the system will meet its performance requirements with 2 banks in operation. This presumes maintenance of the quartz transmissibility and lamp output at or above the levels used in these calculations. As an example, a similar simulation at a quartz transmittance of 40 percent (the lower level determined during the study period) indicates that three banks would be required to meet the required performance goal. This points to the economic benefits (in addition to the obvious performance benefit) derived from keeping a system clean.

OPERATION AND MAINTENANCE EXPERIENCE

As part of its I/A technology assessment program, EPA funded a study in 1984 to evaluate the performance of six UV disinfection systems currently in operation in the U.S. The following discussion briefly summarizes the results of certain aspects of that field study as well as the performance of the Port Richmond facility (9).

The survey results indicate highly variable performance depending on the water quality of the influent and the reactor design. Some facilities such as those at Togus, Maine, Suffern, New York and Pella, Iowa were capable of consistently producing effluent fecal coliform levels of <200/100 ml. Start-up problems including overheating and failure of electrical components such as lamps, ballasts and circuits were experienced at some facilities necessitating redesign. Operational availability of 75% were recorded for experimental units at Port Richmond (9). Twenty-five percent of the downtime was process influent related (foaming) and seventy-five percent of the downtime was related to equipment failure.

Two major considerations in the proper and effective operation of a UV system are: 1) the hydraulics of the unit, and 2) the cleaning methods required for each of the different types of units. The importance of plug flow hydraulics has already been discussed earlier. Suffice it to say that every unit studied in the field suffered in some very fundamental way from axial dispersion resulting in short-circuiting and non-ideal flow. This, in turn, caused a certain degree of non-compliance with coliform limitations. The rest of this report will focus on the cleaning methods in use and the general maintenance requirements of UV systems.

Cleaning of UV Units

An overriding concern in the proper maintenance of a UV reactor is to keep all surfaces through which the UV radiation must pass as clean as possible. The effects of surface fouling on energy utilization efficiency can be quite significant. Maintaining clean UV radiation transmission surfaces is a very important operation and maintenance parameter and fouled or dirty Teflon or quartz tubes can very often be pointed to as the primary reason for the poor disinfection performance of a particular system.

Typically, fused quartz sleeves are rated at a UV transmittance of 90 to 95 percent when new. The transmittance of Teflon tubes will vary with the thickness of tube wall and, under typical designs, one should expect a transmittance between 70 and 85 percent for a virgin Teflon. Current Teflon units are utilizing thinner wall tubes and the virgin UV transmittance is close to 85%. Fouling can occur on both the wetside and the dryside surfaces of both quartz and Teflon tubes. For quartz tubes, waterside fouling on the outside of the tube typically causes the highest percentage of UV intensity loss. Depending on the water quality of the wastewater to be disinfected, fouling of the outside quartz surfaces can be caused by relatively high oil and grease content or by a hardness scaling phenomenon that occurs due to the higher temperature (from the UV lamp) at the outside surface of the quartz tube. The scale on the quartz surfaces, and to a lesser extent on the Teflon surfaces, has been found to be inorganic magnesium and calcium hydroxides and carbonates. Organic fouling is usually caused by a high oil and grease content, but biofilms can also grow on quartz or Teflon surfaces that are not fully irradiated or irradiated non-continuously.

The inner (dry) side of a quartz tube can become fouled due to the passage of air and dirt particles in between the UV lamp and the quartz. Reductions of 15 to 25 percent in the quartz UV transmittance have been noted due to this inside fouling. The outside surfaces of Teflon tubes have been observed to become heavily coated with dust, thereby reducing UV penetration. This is thought to be caused by the highly charged atmosphere between the UV lamp and the Teflon tube, creating an ideal environment for electrostatic precipitation of dust onto the Teflon tubes.

There are basically two approaches to cleaning the quartz and Teflon tube units, chemical and physical. Most of the quartz units recently constructed have been equipped with accessory equipment that attempts to maintain clean outside surfaces on the quartz tubes. The two most common types of accessory equipment for the quartz units are mechanical wipers and ultrasonics. These devices are used on a frequent basis and are considered part of the normal operation of the unit. Chemical cleaning is a task that will typically be required for quartz units on a routine basis. For example, the quartz tube units at Pella, Iowa were mechanically wiped once every three hours and chemically cleaned once every two weeks. The chemical cleaning required one hour per unit.

Cleaning of UV units will be required in all cases to improve the UV transmittance properties of the Teflon or quartz. Teflon has been marketed as a non-fouling material, however, observations and measurements made during this study and prior studies have demonstrated that it is capable of being fouled by secondary wastewater, in some cases quite severely. Frequent visual monitoring of the Teflon tubes in a unit is recommended in order to determine the need for physically and chemically cleaning the tubes. A high pressure nozzle cleaning device is available for scouring fouled surfaces. Swabbing of the tubes, where possible, is also recommended.

The need for cleaning quartz tube UV units has been anticipated since their first usage. Quartz will foul biologically and/or chemically, with the rate of fouling dependent on water quality and whether the UV lamps are on or not. Accessory cleaning equipment, usually ultrasonics or mechanical wipers, are provided with most quartz units. Wipers appear to have a greater potential for keeping the quartz surfaces clean than do ultrasonics, however, neither device will preclude the necessity for chemical cleaning. Designs incorporating quartz UV units should provide for some form of chemical cleaning, preferably a recirculation system.

A solution of the cleaning agent is prepared in the tank with warm water, then recirculated for a period of time, usually overnight, typically with the lamps on. Food-grade citric acid and sodium hydrosulfite are the typical cleaning agents used. Both of these chemicals have been tested for their ability to clean fouled surfaces of quartz, including biologically-fouled and inorganic chemically fouled.

Sodium hydrosulfite is a highly reactive chemical and a strong oxidant. This material appears to be most effective in sealed systems where the cleaning relies solely on contacting the surface under agitated conditions. It must be handled with great care, however, and special requirements will be required to properly store and handle this material and also to dispose of the spent recirculation waste. At Suffern, after an overnight cleaning period, the sodium hydrosulfite, at a concentration of 0.15%, returned the UV transmissibilities of the quartz tubes to like-new conditions, roughly 92% UV transmittance for all of the tubes measured. Even though this chemical is relatively hazardous to handle, it should be considered as one of the chemicals to be used in cleaning a quartz unit.

Citric acid is also a commonly used agent to clean quartz surfaces. A similar testing procedure was followed at Suffern as with sodium hydrosulfite, only using citric acid at a concentration of 0.15% as the recirculation chemical cleaning agent. Although the results of the citric acid cleaning were not as impressive as with the sodium hydrosulfite, nevertheless, citric acid appeared to do an adequate job of cleaning the fouled surfaces of quartz tubes.

Other types of cleaning agents can be considered for use with quartz systems. Diluted mineral acids such as sulfuric or hydrochloric could be used to dissolve inorganic scales and to remove biological films from quartz surfaces. In a couple of locations, it was noted that a chlorine solution was being used in an attempt to clean the surface of the quartz. Chlorine, which is a disinfectant, will not provide the dissolving ability necessary to remove the inorganic scales, although it can remove some types of biological films from the surface of the quartz.

An effective technique for cleaning the teflon tubes was to spray a detergent solution through a high pressure (2,800 kgf/cm^2 - 400 psi) circular spray nozzle on the end of a flexible hose which was snaked through each tube. The technique took an hour for each set of eight, three meter tubes.

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TOXICS TREATABILITY AND CONTROL

The U.S. Environmental Protection Agency (EPA) has established a National "Policy for the Development of Water-Quality-Based Permit Limitations for Toxic Pollutants." The EPA national policy was developed because of data indicating that, even with efficient removal of conventional pollutants, toxic substances in amounts significant to water quality are being discharged through the Nation's wastewater treatment systems. An overall water-quality based toxics control process (15) is available to support the policy of water quality-based permit limitations on toxic pollutants entering treatment plants. The toxics control process includes procedures for evaluating toxics problems in receiving waters, for identifying bioaccumulative potential of the toxics for locating and identifying the responsible point source discharges and for controlling the toxic discharge to eliminate the water quality problem.

Research on toxics in wastewaters by the EPA has revealed that water quality problems associated with point source discharges of toxics exhibit extensive site-specific factors including the amounts, types and sources of toxics, the control effectiveness of existing treatment plants and the characteristics and dilution capacity of the receiving water. Unfortunately, solutions to such water quality problems have complex site-specific aspects.

In the past, the study of toxic discharges into receiving waters by treatment plants had focused chiefly on specific chemicals (16,17). The complexity of many wastewaters, especially municipal wastewaters involving multiple industrial components, however, has also forced the use of biological measurements for assessing (18,19) ecosystem toxicity (overall ecosystem toxic effects) and potential health effects of these wastewaters. Thus an integrated monitoring and control approach using both specific chemical and bioassay techniques is evolving for evaluating toxics water quality problems. The monitoring, especially by bioassays on plant effluent, provides sensitive screening for identifying potential toxic impacts from plant discharges.

RESEARCH APPROACHES

As part of the overall toxics control process, two parallel approaches are being employed to solve the toxics control problems in wastewater treatment. The first approach uses representative specific toxic compounds; the second uses bioassay tools for characterizing toxic impacts of complex mixtures of unknown toxics.

In the first approach, the characterization of removals and effluent concentrations of spiked representative toxics for a range of treatment and management practices involves three levels of research:

- Characterization of specific toxics removals for representative treatment systems and management practices.

- Deterministic assessments of the fate of specific toxics and the inter-relationships (treatability research) of various removal mechanisms in the treatment and management practices.

- Development of predictive correlations from the treatability research and the specific removal studies.

A study of specific chemical removals of representative toxics has recently been completed on conventional secondary treatment and on alternative treatments (20) for marine discharge. Significant treatability assessments(21,22,23) with a number of representative specific compounds have also been completed. One assessment includes predictive methods for fate and removals of toxics in the activated sludge process using experimentally determined kinetic rates for the principal removal mechanisms. Additional treatability assessments with representative chemicals are also underway. A treatability protocol is being developed to permit municipalities and industries to evaluate, at bench scale, the fate and treatability of both specific chemicals and unknown toxic mixtures during wastewater treatment. Finally, in the first research approach, a structure for modeling is beginning to evolve for predicting, from molecular and structural properties of the toxics, the removal and fate of toxics during treatment.

In the second approach, characterization of the toxicity removal capabilities of representative treatment and management practices involves biological assessments (bioassay for ecosystem and health effects) and, to reduce costs of water quality management, assessments with near real-time chemical, bacteriological or enzymatic indicators potentially useful as surrogate bioassays. Studies are ongoing to relate the biological assessment/monitoring, especially of complex toxic mixtures, to treatment operations and management practices including treatment alternatives for marine discharge.

An important step in the overall toxics control process is called a Toxicity Reduction Evaluation (TRE) at individual municipal or industrial wastewater treatment plants. Initiated after confirmation of a toxics water quality problem, the TRE, using an integrated monitoring approach at the treatment plant, determines the toxics sources, the toxics fate during and impact on treatment, the variability of pass-through of the overall toxicity in the effluent wastewater and finally the probable solutions for controlling the toxicity discharge. Case histories of toxicity reduction evaluations are being initiated at the Patapsco Treatment Plant in Baltimore and at other sites for the purpose of developing TRE protocols for use by the wastewater treatment industry.

TOXICS REMOVAL STUDIES

The EPA's Office of Marine and Estuarine Protection is concerned about toxics pass-through in alternative treatment systems for marine discharge cases where removal of conventional pollutants by full secondary treatment is not necessary to meet conventional water quality objectives. Primary interest has been focused on a list of 129 organic and inorganic priority pollutants developed from a Consent Decree between the National Resources Defense Council and the Administrator of the U.S. Environmental Protection Agency (24). A specific toxics removal study (20) using a spiking mixture of 21 volatile and semi-volatile organic priority pollutants and the indigenous trace metals in the Cincinnati wastewater was completed for five alternative systems with the conventional primary-activated sludge treatment system used as a control. The pilot-scale alternative treatment systems included primary treatment plus commercial pulsed-bed filtration, chemical clarification with alum, primary-high rate trickling filter treatment, and single stage aerated and facultative lagoon treatments.

Removal efficiencies for total suspended solids (TSS), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), and total phosphorus (TP) for each alternative system during the study averaged:

	TSS %	COD %	TKN %	TP %
° Primary plus filtration -	86	40	15	44
° Chemical clarification -	89	49	12	75
° High rate trickling filtration -	76	47	14	39
° Aerated lagoon -	85	60	2	19
° Facultative lagoon -	84	65	11	31
° Activated sludge -	93	82	80	58

The removals of the volatile, semivolatile and the trace metal priority pollutants for the alternative treatment systems and for primary and primary-activated sludge treatment are shown for the three pollutant classes in Tables 8, 9 and 10, respectively. Paralleling the removals of conventional pollutants, the primary-activated sludge control system produced the best overall removals of organics, typically 80-90% removal of volatiles, 85-95% removal of semivolatiles and 24 to 82 percent removal of the metals. The facultative lagoon with 26-day hydraulic retention was the best overall alternative treatment system followed by the aerated lagoon (6-day hydraulic retention) for overall control of toxics. Metals removals, however, were not established for chemical treatment and primary plus filtration. Chemical treatment (25) is known to remove most metals very efficiently.

While none of the alternative processes provided overall toxics removal capabilities equal to the activated sludge system, the facultative lagoon provided similar removals of volatile organics and the best observed removal of lindane. The chemical treatment system produced good removals of those organics which partition strongly to the solids in the treatment system. The study revealed that alternative treatment systems, especially those without biological treatment components, would permit significantly increased toxics pass-through.

TABLE 8. VOLATILE ORGANICS REMOVALS BY DIFFERENT PROCESSES (20)

Compound	Inf	Primary Treatment		Primary Plus Filtration		Chemical Clarification		Trickling Filter		Aerated Lagoon		Facultative Lagoon		Activated Sludge	
	µg/L	µg/L	%Rem	µg/L	%Rem	µg/L	%Rem	µg/L	%Rem	µg/L	%Rem	µg/L	%Rem	µg/L	%Rem
Carbon Tetrachloride	69	63	19	56	22	101	-13	26	59	15	70	11	77	13	74
1,1, Dichloroethane	144	144	-	98	32	111	21	94	34	45	68	19	87	8	94
1,1, Dichloroethylene	212	188	5	138	22	150	25	85	58	83	60	35	85	14	92
Chloroform	135	143	-7	113	18	106	20	102	25	53	61	31	80	18	86
1,2 Dichloroethane	153	135	7	96	34	109	22	93	33	45	70	15	90	22	84
Bromoform	90	83	18	119	2	114	-6	41	57	15	80	22	84	29	65
Ethylbenzene	111	102	9	70	35	73	31	31	71	27	70	12	96	6	93
Average Removal of Volatiles			7		24		14		48		68		86		84

TABLE 9. REMOVAL OF SEMIVOLATILE ORGANICS BY DIFFERENT PROCESSES (20)

Compound	Inf	Primary Treatment		Primary Plus Filtration		Chemical Clarification		Trickling Filter		Aerated Lagoon		Facultative Lagoon		Activated Sludge	
	µg/L	µg/L	%Rem	µg/L	%Rem	µg/L	%Rem	µg/L	%Rem	µg/L	%Rem	µg/L	%Rem	µg/L	%Rem
Bis(2 ethylhexyl)-phthalate	168	90	37	47	75	15	89	39	75	34	77	30	80	18	87
Dibutylphthalate	73	68	2	56	22	47	31	52	26	44	40	14	78	7	88
Naphthalene	108	92	13	86	20	79	23	74	28	36	64	13	87	4	97
Phenanthrene	95	76	21	48	49	24	74	51	45	40	55	16	82	4	95
Pyrene	104	84	18	39	61	12	88	48	54	36	63	25	75	5	95
Fluoranthene	104	80	22	39	61	13	87	49	53	36	64	23	77	5	95
Isophorone	89	77	4	74	8	80	5	72	17	68	22	62	25	2	98
Bis(2-chloroethyl)-ether	143	122	6	120	20	114	17	132	-	102	23	78	43	30	80
p-Dichlorobenzene	93	75	19	66	29	66	28	58	36	31	65	12	87	5	94
Phenol	126	112	23	131	4	99	21	64	50	84	30	18	86	14	86
2,4 Dichlorophenol	228	133	45	300	-	92	60	200	31	155	48	65	73	1	99
Pentachlorophenol	84	78	16	90	19	50	50	82	4	57	37	20	74	3	96
Lindane	39	40	-4	-	-	32	17	34	13	22	42	7	80	31	18
Heptachlor	39	26	32	-	-	14	64	18	53	13	66	13	62	13	65

TABLE 10. METALS REMOVALS BY DIFFERENT PROCESSES (20)

Metal	Inf	Primary Treatment		Trickling Filter		Aerated Lagoon		Facultative Lagoon		Activated Sludge	
	μg/L	μg/L	%Rem	μg/L	%Rem	μg/L	%Rem	μg/L	%Rem	μg/L	%Rem
Cr	221	206	7	107	52	65	71	46	79	40	82
Cu	345	279	19	137	60	89	74	71	79	61	82
Ni	141	136	4	98	30	91	35	81	43	81	43
Pb	165	115	30	86	48	70	50	82	50	58	65
Cd	25	22	12	18	28	-	-	17	32	19	24

TREATABILITY RESEARCH

The completed studies (21,22,23) on treatability have evaluated the relative removals of selected toxics by the three principal removal mechanisms--volatilization, biodegradation and sorption--in the activated sludge process. Two of the studies (21,22) also evaluated the impact of the selected toxics on anaerobic digestion. One study (23) assessed the effect of powdered carbon adsorption on toxic removals in the activated sludge system. These studies have generated experimental kinetic data on the competitive removal rates of the principal removal mechanisms and have provided insight into effects of operating design factors such as sludge retention time (SRT) on the toxic control capabilities.

Data from the Purdue studies (21,22) on 8 representative priority organics in Table 11 reveal that efficient (often more than 99%) removal of the organics was achieved after treatment using acclimated biomass, even for highly chlorinated organics such as pentachlorophenol (PCP). The data further reveal that biodegradation was the principal removal mechanism. The sorption mechanism contributed approximately 20% of the removal of bis(2-ethylhexyl) phthalate (BEHP) for all operating SRT except 3 days. At the low 3-day SRT, sorption was responsible for 55% of the removal. The volatilization mechanism contributed from 20 to 80% of the removals of toluene (TOL) and naphthalene (NAPTH) with the high volatilization contributions occurring at the high SRTs of 7 and 11 days. The modest removal contributions of the sorption mechanism in the activated sludge process indicates that biodegradation by acclimated biomass will degrade even those organics with high octanol water partition coefficients such as bis(2-ethylhexyl) phthalate. The study found that the rates of volatilization for moderately volatile organics such as toluene and naphthalene were competitive with the rates of biodegradation.

Data on acclimated anaerobic digestion of the same 8 organics revealed that parachlorometacresol (PCMC) was partially refractory to the anaerobic process with 30 to 40% remaining after digestion. Four organics, pentachlorophenol, dimethyl phthalate (DMP), dinitro-orthocresol (DNOC) and bis(2-ethylhexyl) phthalate were reduced in concentration by more than 99%; chlorobenzene (MCB) and naphthalene were reduced by more than 95% and toluene, by 91%. In the anaerobic process, variable amounts of these organics were removed by the sorption and volatilization mechanisms.

Data from the University of Michigan studies (23) on 8 priority organics in Tables 12 and 13 confirm the importance of the biodegradation mechanism in removing organics of moderate volatility. For the organics studied, sorption contributed little to the removal process. The relative importance of the biodegradation and volatilization mechanism shown in Table 12 revealed that volatile but non-biodegradable organics such as 1,2,4-trichlorobenzene are removed effectively from the water by the volatilization mechanism. Non-biodegradable and poorly sorbable organics such as lindane pass through the treatment process. The relative importance of the volatilization and biodegradation mechanisms in the removal of the organics depended upon the

TABLE 11. FATE OF ORGANICS IN ACCLIMATED ACTIVATED SLUDGE (22)

Compound	SRT Days	Compound in Feed mg/L	Compound Remaining in Eff. µg/L	Affected Other COD Removal?	Stable Compound Removal?	Fate of Compound: Percentage In Effluent	Sorbed on Solids	Vola-tilized	Bio-Degraded
PCP	3	20	214	No	No	1.07	0.31	0.03	98.6
	5	20	105	No	No	0.53	0.15	0.03	99.3
	7	20	68	No	No	0.34	0.10	0.03	99.5
	11	20	64	No	Yes	0.32	0.08	0.04	99.6
MCB	3	16.3	<5	No	Yes	<0.03	2×10^{-4}	<7	>93
	5	16.3	<5	No	Yes	<0.03	2×10^{-4}	<11	>89
	7	16.3	<5	No	Yes	<0.03	2×10^{-4}	<16	>84
	11	16.3	<5	No	Yes	<0.03	2×10^{-4}	<21	>79
DMP	3	20	<5	No	Yes	<0.03	$<10^{-2}$	$<10^{-2}$	>99.9
	5	20	<5	No	Yes	<0.03	$<10^{-2}$	$<10^{-1}$	>99.9
	7	20	<5	No	Yes	<0.03	$<10^{-2}$	$<10^{-1}$	>99.9
	11	20	<5	No	Yes	<0.03	$<10^{-2}$	$<10^{-1}$	>99.9
BEHP	3	2.64	138	No	No	5.2	55.4	$<10^{-2}$	39.4
	5	2.64	75	No	Yes	2.8	15.5	$<10^{-2}$	81.7
	7	2.64	66	No	Yes	2.5	13.3	$<10^{-2}$	84.2
	11	2.64	68	No	Yes	2.6	18.7	$<10^{-2}$	78.7
TOL	3	26.1	<5	No	Yes	<0.02	$<10^{-2}$	<21	>79
	5	26.1	<5	No	Yes	<0.02	$<10^{-2}$	<32	>68
	7	26.1	<5	No	Yes	<0.02	$<10^{-2}$	<48	>52
	11	26.1	<5	No	Yes	<0.02	$<10^{-2}$	<60	>40
NAPTH	3	4.24	<5	No	Yes	<0.12	0.23	<29	>71
	5	4.24	<5	No	Yes	<0.12	0.19	<32	>68
	7	4.24	<5	No	Yes	<0.12	0.19	<68	>32
	11	4.24	<5	No	Yes	<0.12	0.20	<84	>16
PCMC	3	20	7.9	No	Yes	0.08	3.04	$<10^{-2}$	96.9
	5	20	4.8	No	Yes	0.05	0.95	$<10^{-2}$	99.0
	7	20	4.0	No	Yes	0.04	0.83	$<10^{-2}$	99.1
	11	20	5.0	No	Yes	0.05	1.26	$<10^{-2}$	98.7
DNOC	3	20	666	No	No	6.7	0.11	0.47	92.7
	5	20	760	No	No	7.6	0.17	0.58	91.7
	7	20	301	No	Yes	3.0	0.02	0.32	96.7
	11	20	85	No	Yes	0.85	$<10^{-2}$	0.14	99.0

TABLE 12. FATE OF TOXIC ORGANICS IN ACCLIMATED ACTIVATED SLUDGE BIOREACTORS (23)

Compound	Percent of Influent			
	Effluent	Off-Gas	Biosorbed	Biodegraded
Benzene	<1	16	0	84
Toluene	<1	17	0	83
Ethylbenzene	<1	22	0	78
o-Xylene	<1	25	0	75
Chlorobenzene	<1	20	0	80
1,2-Dichlorobenzene	6	59	0	35
1,2,4-Trichlorobenzene	10	90	<1	0
Nitrobenzene	2	<1	0	98
Lindane	96	0	4	0

TABLE 13. FIRST ORDER BIODEGRADATION RATE COEFFICIENTS CALCULATED FROM REACTOR MASS BALANCES (23)

Compound	SRT (days)	Biodegradation Rate Coefficient, k_b (min^{-1})	Volatilization Rate Coefficient, k_v (min^{-1})
Benzene	3	0.43	0.081
	6	0.43	0.075
	12	0.49	0.075
Toluene	6	0.45	0.078
	12	0.42	0.077
Ethylbenzene	6	0.37	0.091
	6	0.43	0.087
	12	0.43	0.087
o-Xylene	6	0.28	0.062
	6	0.20	0.060
	12	0.21	0.060
Chlorobenzene	6	0.26	0.050
	12	0.26	0.052
Nitrobenzene	6	0.12	<0.001
	6	0.09	<0.001
1,2-Dichlorobenzene	6	0.017	0.025
	12	0.018	0.026

relative kinetic rates of the two removal mechanisms (Table 13). Dichlorobenzene, a relatively slowly degradable organic, exhibited the highest volatilization removal contributions. Acclimation periods for the organics ranged from 7 to 14 days.

The addition of powdered activated carbon (PAC) provided enhanced removals of 1,2-dichlorobenzene, 1,2,4-trichlorobenzene, and lindane. Powdered carbon addition effected reductions in both the effluent and off-gas concentrations of volatile, non-biodegradable compounds. PAC doses as small as 25 to 50 mg/L produced significant improvements in non-biodegradable toxics removal compared with control activated sludge systems. Greater than 90% removals occurred at influent carbon doses of 100 mg/L. The addition of PAC at influent doses less than 100 mg/L did not enhance the removal of the biodegradable toxic organics.

PAC bioreactor studies in the University of Michigan study, conducted at solids retention times (SRT's) of 0.25 to 12 days and a 50-mg/L carbon dose, showed that the removal of non-biodegradable toxics was the same over the range of SRT's studied. The most important operating parameter with respect to removals of toxics was the influent PAC concentration.

A major EPA inhouse research effort has recently been initiated to expand the data on specific removal contributions of the principal removal mechanisms in the activated sludge process. Studies on biodegradation using bench scale completely mixed reactors and electrolytic respirometry techniques (Figure 13) are underway on selected organics to ultimately permit prediction of the biodegradability from molecular properties and structures. The electrolytic respirometry techniques readily provide acclimation data, toxics inhibition data, and biodegradation kinetics. Parallel kinetic studies with appropriate organics on raw solids, acclimated and unacclimated biomass and digester solids are also being conducted to provide the needed removal contributions from the sorption and volatilization mechanisms.

The inhouse research effort is also evaluating the fate and removal of metals in the conventional primary-activated sludge process. The sorption of metals on raw solids, biomass and digestion solids is being evaluated in equilibrium and kinetic studies. Typical empirical adsorption isotherms for metals on activated sludge biomass are shown in Figure 14. The desorption of metals and organics from sludges, both in seawater and freshwater is also being evaluated.

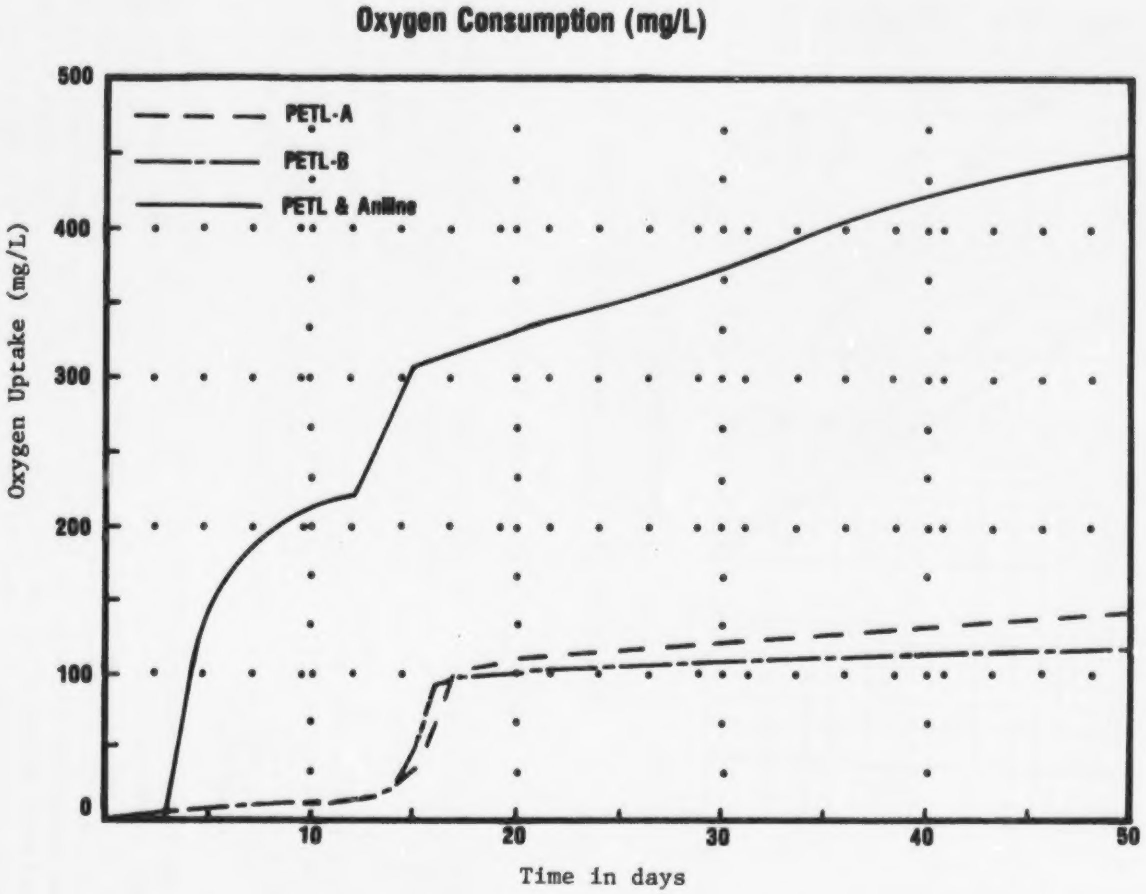

Figure 13. Oxygen consumption of aniline and pentaerythritol (PETL).

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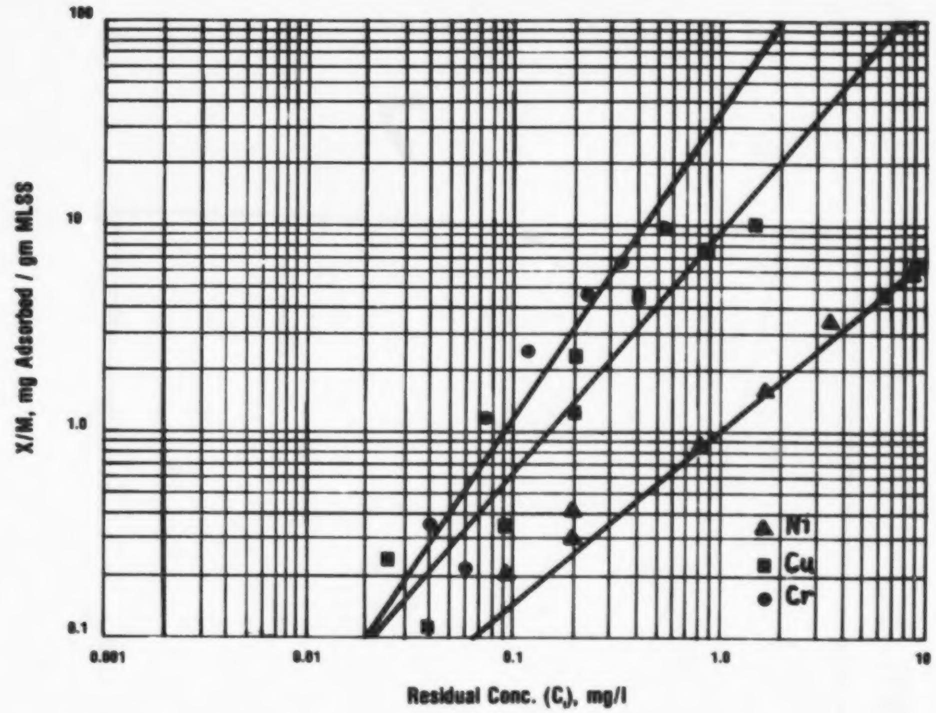

Figure 14. Adsorption isotherms for metals on aerobic biomass.

THE TOXICITY REDUCTION EVALUATION (TRE)

The biomonitoring screening of point source discharges and the follow-on studies to evaluate the impact of the toxic discharge on the receiving water establish the control requirements for the TRE at the treatment plant. The control requirements usually are presented as integrated toxicity levels that must be achieved by the point source discharge to eliminate the toxic water quality impact. Such levels will ultimately be established using a statistical approach that will be based upon desired water quality and the historical variability of the receiving water flow or dilution capacity.

With the desired toxicity levels established for the discharge, the overall elements of a typical TRE at the treatment plant are presented in Table 14. The first step is the evaluation of the toxicity reduction occurring across the treatment plant and the determination of the probable cause of the excessive toxicity in the discharge. A key determination is whether operational deficiencies at the plant significantly contribute to the toxicity pass-through or whether the presence of toxicity refractory to the plant's treatment processes principally produces the excessive toxicity.

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The next step in the TRE involves two elements, occurring in parallel, in which the toxicity is traced to its sources and the important toxicity components, if possible, are identified and the ecosystem and the health effect biomonitoring assays, in-plant toxicity monitoring assays, and specific chemical analytical techniques are all employed to achieve the goals of this step.

Finally, an evaluation of the control alternatives to eliminate the excessive pass-through is conducted. The evaluation includes assessing possible industrial process modifications to minimize release of the toxics, the use of pretreatment approaches to control the toxics before discharge to the central plant, and improvement of the central plant's operations to control the toxicity.

The research approach to developing appropriate protocols on TRE for use in municipal wastewater treatment involves:

- Toxicity reduction studies on pilot and full-scale treatment systems to determine representative toxicity reduction capabilities of municipal wastewater treatment processes.

- Case histories of research TRE at selected full-scale treatment plants to assess the capabilities of the monitoring tools and the treatability and pretreatment approaches likely to be incorporated in the municipal protocols for TRE.

- Research on techniques to enhance the toxicity reduction capabilities of the central treatment plant.

TABLE 14. ELEMENTS OF A TOXICITY REDUCTION EVALUATION

- Treatment Plant Evaluation of Causes of Toxicity Pass-through.
  - A. Plant Operations Deficiency.
  - B. Presences of Refractory Toxicity.

- Tracing of Toxicity to Sources.
  - A. Bioassay Monitoring.
  - B. Alternative Monitoring Techniques.

- Identification of Toxicity Components.
  - A. Specific Chemical Identification.
  - B. Bioaccumulative Potential.

- Evaluation of Control Alternatives.
  - A. Industrial Process Modifications.
  - B. Pretreatment Alternatives.
  - C. Central Treatment Plant Control of Toxicity.

Parallel research is also ongoing on TRE protocols and case histories for industrial wastewater treatment. The parallel research will include the assessment of approaches for industrial process modification to minimize toxicity release. These industrial techniques will be appropriately referenced in the protocols on the municipal TRE.

TOXICITY REDUCTION CAPABILITIES

Pilot-scale research using wastewater spiked with representative toxic mixtures has revealed a good capability of the central treatment plant to reduce toxicity, but toxicity penetration into the plant effluent does occur. As an example of the treatment plant capabilities, acute toxicity reductions (18) of 100 percent based upon Fathead Minnow bioassays (26) were achieved in a pilot-scale primary-activated sludge treatment plant for the indigenous (metals and organics) toxicity in an industrialized raw Cincinnati wastewater. The spiking at 50 µg/L levels of each compound in a mixture of 22 of the Agency's priority organic pollutants into the same wastewater, however, produced an increase in the toxicity of the raw wastewater and substantial pass-through, even with acclimation, of residual toxicity (Table 15). Selected compounds, most importantly lindane in the spike, were refractory to the treatment processes. High conventional pollutant removals (17) were always achieved during this study, independently of the spiked toxics.

Pilot and full-scale studies (19), using Ames (27) and mammalian cell (28) assays have revealed the presence and pass-through of mutagenic materials in municipal wastewaters. The mutagenic materials were extracted from several Cincinnati wastewaters with methylene chloride, first at pH 2, then at pH 11. The concentrated extracts were combined and solvent transferred into dimethyl sulfoxide (DMSO) to eliminate the effect of methylene chloride on the subsequent mutagenicity assays. The results of the Ames assays (Table 16) revealed substantive but variable amounts of mutagenicity in the influent wastewaters, ranging to approximately 20,000 revertants per liter.

The mutagenicity removals in these tests with efficient conventional treatment, varied from substantive removal to essentially no removal of the mutagenicity. This study and others also revealed that wastewaters of domestic origin have extractable mutagenicity levels, usually around 500 revertants per liter of effluent.

The high number of not detectable (N.D.) responses in these studies on the raw wastewaters or primary effluents are usually caused by cytotoxic effects from the large amounts of extracted organics in the extract. Unlike the secondary effluent tests, the cytotoxic effects prevented testing of the extracted organics from the raw or primary wastewater over an appropriate concentration range to properly evaluate the mutagenicity. Additional tests with mammalian cell assays (28) using Syrian hamster cells reveal qualitatively similar responses between the two assays. The results from the mammalian cell assays suggest higher removals of mutagenicity measured by the mammalian cell compared with the results from the Ames test.

Currently, the assay results from the Ames test or other health effects screening assays have not been related to health effects risk. Research, currently ongoing, is attempting to establish a link between health risks and the screening assay results.

TABLE 15. ACUTE TOXICITY* IN WASTEWATER TREATMENT

Control System			Spiked System**		
LC-50 percent Inf.	Eff.	% Toxicity Reduction***	LC-50 Percent Inf.	Eff.	% Toxicity Reduction***
30	> 100	100	4.6	13.1	65
11	> 100	100	2.7	16.1	83
9.3	> 100	100	9.5	35.5	73
30	> 100	100	4.5	6.6	32
10.2	> 100	100	4.3	9.4	55
18.5	> 100	100	5.8	30	81
10.1	> 100	100	6.5	30	78
20.6	> 100	100	1.9	8.0	76

*Fathead Minnow acute toxicity. (Data developed by the Environmental Monitoring and Support Laboratory-Newtown Facility, Cincinnati, Ohio.)

**Spiked with 22 priority organics.

$$\text{***\% Toxicity Reduction} = \frac{[(1/\text{LC-50})\ \text{inf} - (1/\text{LC-50})\ \text{eff}]}{(1/\text{LC-50})\ \text{inf}} \times 100$$

At an LC-50 in the effluent of > 100; equation does not apply and the acute toxicity reduction is considered as 100%.

TABLE 16. MUTAGENICITY IN THE AMES TEST OF MUNICIPAL WASTEWATER SAMPLES AT VARIOUS TREATMENT STAGES

Treatment Plant	Wastewater Type	Sample Designation (Date)	Treatment Stage	Total Liters Extracted	Conc.[a] (mg/L)	TA98 Mutagenicity			TA100 Mutagenicity		
						net revertants/mg		net[b] revertants/liter	net revertants/mg		net[b] revertants/liter
						-S9	+S9		-S9	+S9	
Mill Creek T&E Facility	Industrial/Domestic	Series A_1 09/02/81	Raw Wastewater	2	48.8	173	381	18,593	N.D.	N.D.	-
			Primary Effluent	2	41.8	1,057	524	21,903	N.D.	N.D.	-
			Secondary Effluent	6	4.9	169	1,376	6,674	N.D.	258	1,251
			Secondary + Cl_2	6	4.6	196	1,768	8,133	N.D.	409	1,881
		Series A_2 09/09/81	Raw Wastewater	2	66.5	N.D.	182	12,103	N.D.	N.D.	-
			Primary Effluent	2	46.0	77	392	18,032	N.D.	N.D.	-
			Secondary Effluent	6	4.6	5,645	4,074	18,944	1,836	1,035	4,813
			Secondary + Cl_2	6	4.0	6,370	4,318	17,272	2,246	2,146	8,584
Mill Creek Plant	Industrial/Domestic	Series B_1 08/31/82	Raw Wastewater	8[c]	91.0	N.D.	89	8,099	N.D.	N.D.	-
			Secondary Effluent	50[c]	7.7	417	353	2,718	N.D.	244	1,879
		Series B_2 06/20/83	Primary Effluent	23	70.4	N.D.	129	9,082	N.D.	N.D.	-
			Secondary Effluent	86	8.7	693	761	6,621	928	1,540	13,398
Muddy Creek Plant	Domestic	Series C_3 01/11/83	Raw Wastewater	24[c]	36.8	N.D.	N.D.	-	N.D.	N.D.	-
			Secondary Effluent	92[c]	2.2	161	175	385	208	284	625

N.D. = not detectable (i.e. response at any sample dose level was less than 2-fold above concurrent solvent control).

[a] Refers to the concentration of extractable organics based on the residue weights of the extracts.

[b] Based on the mutagenicity values from the assays with S9 activation.

[c] Extraction at pH 11.0 was omitted.

TOXICITY REDUCTION SURVEY

A toxicity reduction survey is now being completed at six municipal wastewater treatment plants in the State of Ohio. The plants were selected for the survey to represent wastewaters of chiefly domestic origin, wastewaters with modest industrial contributions, and wastewaters with substantial industrial contributions. The toxicity entering and leaving the treatment plants were measured using static renewal seven-day acute-chronic Fathead Minnow (29) and Ceriodaphnia (30) assays for assessing ecosystem effects, the Ames test and mammalian cell assays cells for mutagenicity screening, and the Sister Chromatid Exchange assay (31) using Chinese hamster ovary cells for genotoxicity. Analyses for conventional pollutants and for specific toxic trace metals and individual organics were also provided. The State of Ohio's Environmental Protection Agency also conducted fish diversity studies using electroshock techniques on the receiving waters associated with some of the treatment plants.

Examples of representative toxicity reductions are shown in Tables 17 and 18 for the wastewater treatment plant at Akron, Ohio and the Little Miami Plant in Cincinnati. The Akron Plant, with substantive industrial contributions to the wastewater, exhibited the highest influent toxicity of all the surveyed plants with no effect concentrations (NOEC) ranging from 0.3 to 1 percent of the influent wastewater. The Akron plant, which was achieving nitrification and meeting its conventional pollutant removal requirements during the survey, also achieved efficient toxicity removal with the NOEC ranging from 10 percent of the effluent for acute (survival) effects on Fathead Minnows to 100 percent effluent for acute (survival) effects on both the Fathead Minnow and the Ceriodaphnia assays. The NOEC of 10 and 30 percent in the Akron effluent suggests only a modest toxicity in the discharge to the receiving water ecosystem.

The Little Miami Plant, with modest industrial contributions to its wastewater, exhibited less toxicity in the influent wastewater but also achieved little toxicity reduction across the treatment plant. The Little Miami effluent with NOEC of 1 to 10 percent effluent for the Ceriodaphnia assay was the most toxic of the effluents evaluated in the survey, even though the plant was meeting its conventional pollutant removal requirements. Finally, the data presently available on plants in the survey with wastewaters of chiefly domestic origin revealed modest toxicity in the influent and essentially no aquatic toxicity in the effluent.

To assess the probable effect of the effluent on the receiving stream, however, the stream dilution capacity must be considered. For the Akron Plant, the effluent contributes more than 50 percent of the stream flow during summer low flow conditions. In contrast, the Little Miami effluent provides less than 1 percent of the flow to the Ohio River, even at summer low flow conditions. With substantive dilution, the Little Miami toxicity discharge is unlikely to affect the Ohio ecosystem. The effluent-dominated Cuyahoga River at Akron, however, could be affected by the modest toxicity discharges from the Akron Plant.

TABLE 17. TOXICITY REDUCTION AT AKRON, AS NO OBSERVED EFFECT CONCENTRATIONS* (NOEC), IN PERCENT EFFLUENT

Sample	Fathead Minnows				Ceriodaphnia			
	Survival		Growth		Survival		Reproduction	
	8/84	5/85	8/84	5/85	8/84	5/85	8/84	5/85
Influent	<0.3	1.0	0.3	1.0	0.3	1.0	0.3	1.0
Secondary Effluent	30	10	10[a]	30	≥30	30	30	30
Chlorinated Secondary	10	10	≥100[b]	≥100	30	≥100	30	30
Dechlorinated Secondary	≥100	10	≥100[b]	30	30	≥100	30	30

[a] - CL_2 may have been present in sample.
[b] - Low control value, NOEC may be lower.
*All NOEC data are subject to final statistical review. (Data developed by the Environmental Monitoring and Support Laboratory-Newtown Facility, Cincinnati, Ohio.)

TABLE 18. TOXICITY REDUCTION AT LITTLE MIAMI, AS NO OBSERVED EFFECT CONCENTRATIONS* (NOEC), PERCENT EFFLUENT

Sample	Fathead Minnows				Ceriodaphnia			
	Survival		Growth		Survival		Reproduction	
	12/84	5/85	12/84	5/85	12/84	5/85	12/84	5/85
Influent	10	10	10	10	3	10	0.3	3
Secondary Effluent	≥100	≥100	30	30	1	10	1	3
Chlorinated Plant Effluent	30	30	30	30	1	10	1	3
Dechlorinated Plant Effluent	30	30	30	30	1	10	3	3

*All NOEC data are subject to final statistical review. (Data developed by the Environmental Monitoring and Support Laboratory-Newtown Facility, Cincinnati, Ohio.)

The fish diversity studies (Figure 15) on the Cuyahoga River, indeed, indicated a major toxic impact on the fish population beginning at the point of discharge of the Akron Plant. Upstream of the discharge, the fish population was found to be good. The fish populations in the River's tributaries also, usually ranged from fair to good. The fish diversity study, conducted three times during the Summer of 1984 and spanning the time of the toxicity survey, revealed a persistent loss of fish in the Cuyahoga for about 10 miles down stream of the Akron discharge and a second toxics impact when the River entered the Cleveland Ship Channel at Lake Erie. No other significant wastewater discharges enter the Cuyahoga immediately below Akron, as the River passes through the Cuyahoga National Park Recreational Area. In addition, appropriate measurement of stream dissolved oxygen (D.O.) and ammonia concentrations revealed no D.O. or ammonia toxic impacts on the River immediately below Akron. Overall, the stream fish diversity indicated major toxicity impacts on the River, perhaps the most significant impacts in the State of Ohio.

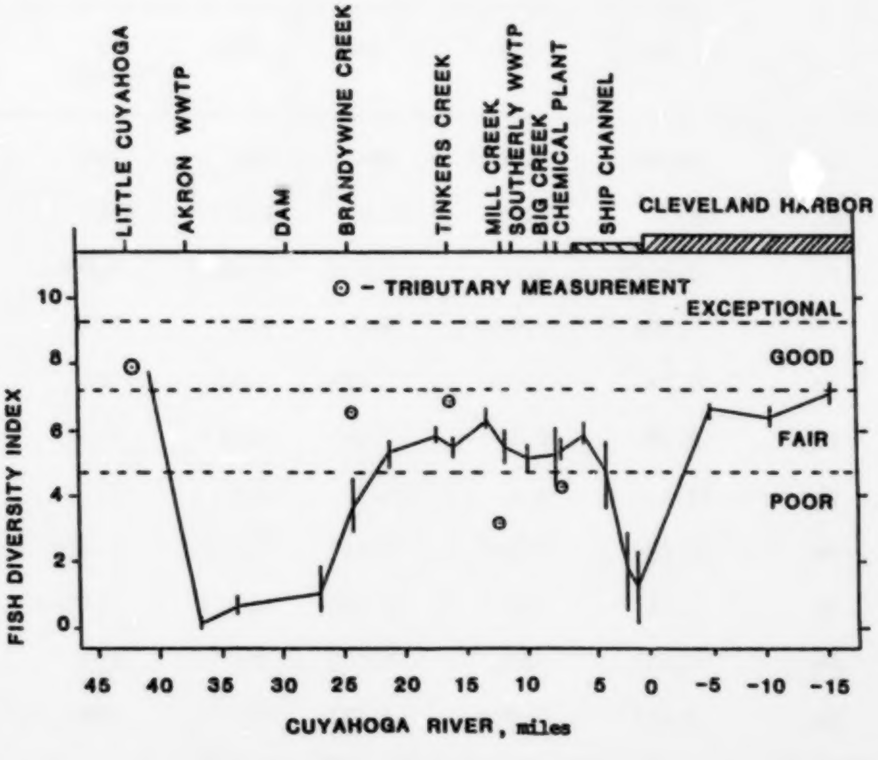

Figure 15. Toxicity impact on the Cuyahoga River.
(Data developed by the Ohio EPA.)

Other data obtained during the survey revealed low metals concentrations (Table 19) and very modest concentrations of specific extractable organic residuals in the Akron plant's effluent (Table 20). In addition, the relatively complex GC chromatograms on the highly toxic plant influent, and the relatively "clean" GC chromatograms of the effluent (Figures 16 and 17) supported the observed efficient toxicity reduction achieved by the treatment plant. Further, the Ames test screening for mutagenicity (Table 21) also revealed only modest mutagenicity in the effluent, indeed not significantly different from effluents from plants treating chiefly domestic wastewater. Unfortunately, because the plant's influent is highly toxic its mutagenicity could not be determined.

TABLE 19. AKRON METALS REMOVAL*

Metal	Concentration (mg/L)					
	1984		1985			
	Inf.	Eff.	Inf.	Eff.	Up Stream	Down Stream
As	BDL**	0.0077	BDL	BDL	BDL	BDL
Ca	90.3	75.8	95.6	72.1	65.1	67.6
Cd	0.0012	BDL	0.028	0.0094	0.0041	0.0097
Cr	.088	.016	BDL	BDL	BDL	BDL
Cu	0.19	.026	.029	.011	BDL	BDL
Fe	0.28	0.17	2.14	0.913	0.583	0.633
Mg	22.7	14.5	24.2	16.5	15.7	16.5
Mn	0.204	0.102	0.417	0.313	0.200	0.165
Ni	0.34	BDL	0.022	0.013	0.0062	0.010
Pb	0.057	BDL	0.046	BDL	BDL	BDL
Zn	0.447	0.038	1.333	BDL	BDL	BDL

*Data developed by the Water Engineering Research Laboratory-Cincinnati, Ohio.

**BDL - Below detection limit.

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TABLE 20. EXTRACTABLE ORGANIC ANALYSIS OF AKRON CHLORINATED SECONDARY*

No.	Compound	µg/L
1	d(10)anthracene	Internal. Std.
2	n,n-dimethylformamide	8
3	tetrachloroethene	65
4	1,6-hexanediol	10
5	1-cyclohexen-1-ol	7
6	2-cyclohexen-1-one	4
7	benzaldehyde	6
8	unknown	5
9	unknown	4
10	hydrocarbon	3
11	hexane	2
12	unknown	2
13	5-hexen-2-ol	7
14	benzothiazole	4
15	unknown	2
16	unknown	24
17	unknown	2
18	unknown	2
19	unknown	5
20	hexanedioic acid, bis(2-ethylhexyl) ester	50
21	bis(ethylhexyl)phthalate	7
22	unknown	2

*Data developed by the Water Engineering Research Laboratory-Cincinnati, Ohio.

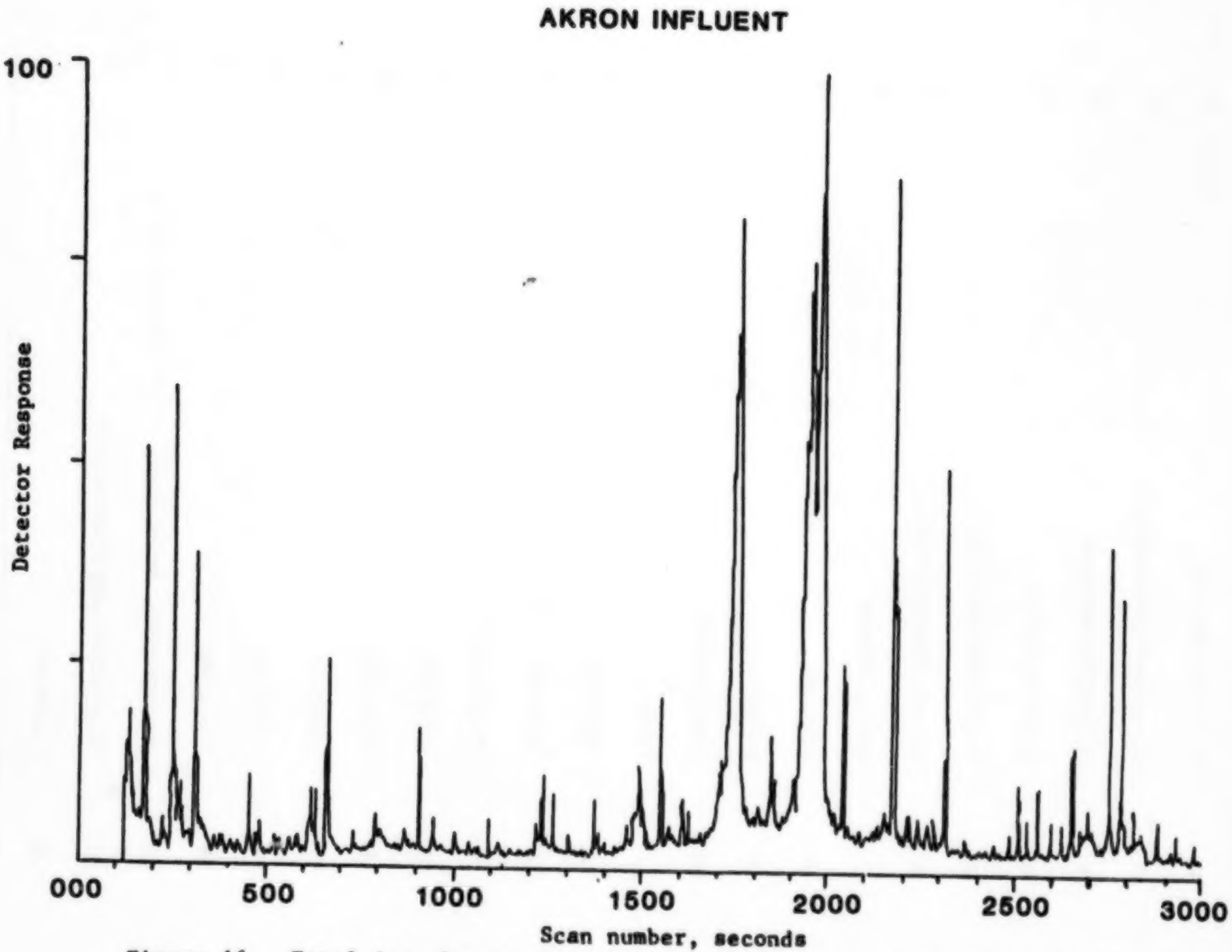

Figure 16. Total ion chromatogram on raw wastewater. (Data developed by the Water Engineering Research Laboratory, Cincinnati, Ohio.)

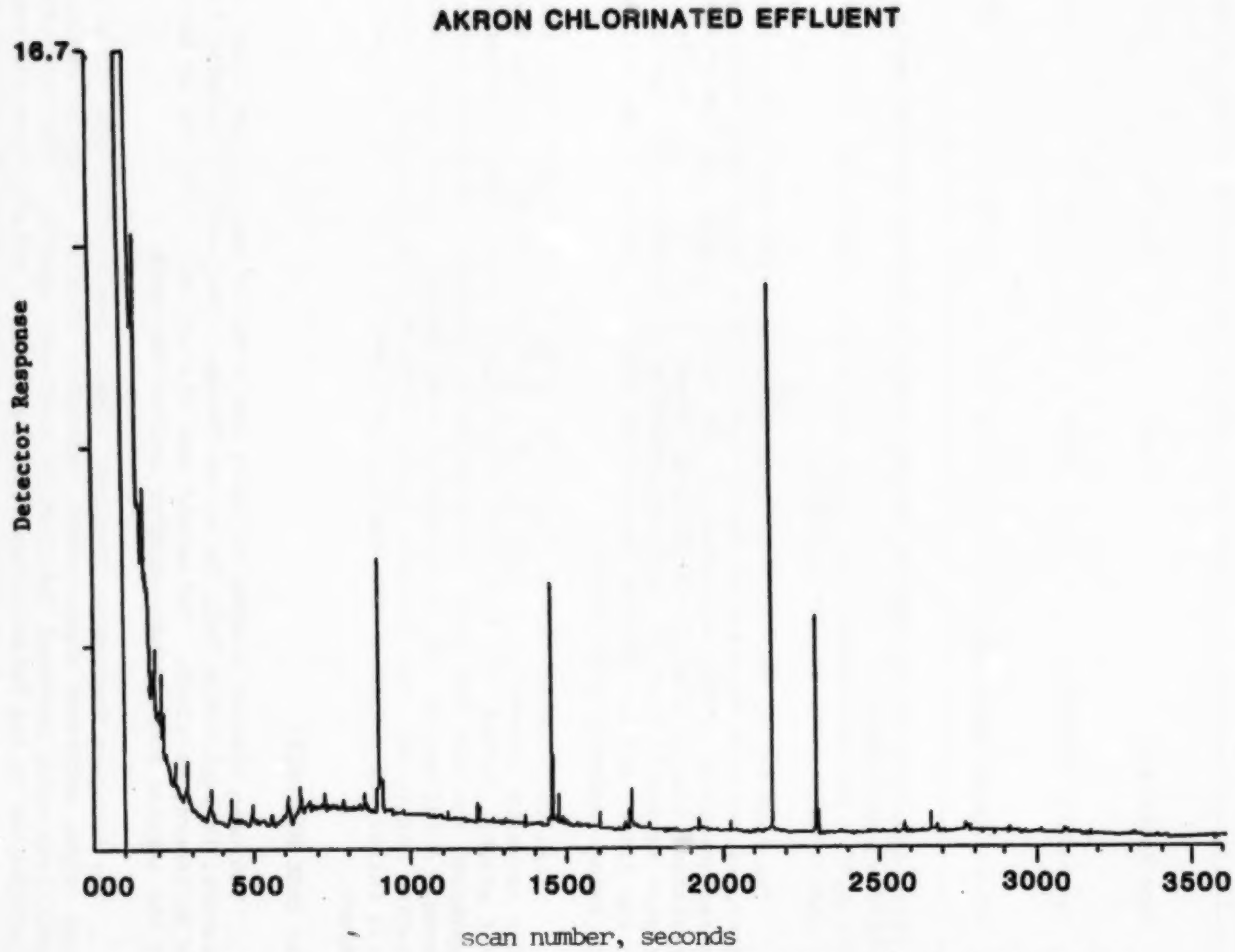

Figure 17. Total ion chromatogram on plant effluent. (Data developed by the Water Engineering Research Laboratory, Cincinnati, Ohio.)

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TABLE 21. AKRON MUTAGENICITY STUDY*

Sample (1984)	Concentration of Extractable Organics mg/L	AMES REV**/mg	Mutagenicity Rev*/L
Raw Wastewater	45.09	N.D.***	----
Secondary Effluent	3.66	140	512
Chlorinated Secondary	3.02	130	393

*Data developed by the Health Effects Research Laboratory-Cincinnati, Ohio.
**REV = revertants.
***N.D.** = Not detectable (i.e., response at any sample dose level was less than 2-fold above solvent control).

The toxicity in the Akron effluent with the relatively "clean" wastewater, as measured by residual metals and specific extractable organics, raised questions about the sources of the toxics causing the observed and persistent loss of fish in the Cuyahoga River at Akron. Thus, studies to measure variability of the effluent toxicity, to reconfirm the lack of fish in the River, and to identify responsible specific toxics in the effluent are being conducted this summer.

Finally, a preliminary review of the plant's operating records has also revealed intermittent bypassing of combined sewer flows at the treatment plant. Indeed, the bypassing of the highly toxic plant influent could represent the most important contribution to Cuyahoga's toxicity problem at Akron. A full-scale TRE, as a research case history, is now under consideration for Akron. The decision to use Akron as a detailed case history will follow the review of the ongoing confirmatory studies on the toxicity impact.

TRE CASE HISTORIES

Two case history studies on TRE's are about to begin. The first case history, to begin this fall, is at the Patapsco Wastewater Treatment Plant in Baltimore, Maryland. The second case history will likely be at Akron, if the ongoing confirmatory studies confirm the need.

The Patapsco Wastewater Treatment Plant, completed in 1982, is a 70 mgd pure oxygen activated sludge plant, currently treating 35 mgd at design conditions using one-half the plant's treatment capacity. The industrial contribution to the Patapsco municipal wastewater, chiefly from the organic chemicals industries in Baltimore, currently totals about 30 percent of the plant influent. The case history TRE for Baltimore was selected not only because of substantive influent toxicity at the treatment plant and a history of intermittent pass-through of that toxicity (Tables 22 and 23) but also because of a historical and ongoing in-plant toxicity monitoring and control program.

Two sources of wastewater, a chiefly industrial flow (IPI) and a flow (SWD) from domestic-commercial sources are combined to form the plant influent. The in-plant monitoring MICROTOX procedure (32) on daily composite samples at the plant uses a maximum of 45.5 percent wastewater in the test. For low toxicity levels that require more than 45.5 percent wastewater to produce a measurable EC_{50}, the EC_{50} of the sample was recorded as > 45.5 percent. Thus, the low toxicity effluents and the domestic-commercial influent flows (SWD) do not always have a defined EC_{50}. To provide the monthly average perspective given in Table 22, EC_{50} values of > 45.5 percent were included in the monthly averaging procedure as 45.5 and the monthly average EC_{50} in the table was presented as a greater than (>) value. The number of days in the month that an EC_{50} lower than > 45.5 occurred is also included in Table 22. The averaged monthly EC_{50} values for the effluent are all less than > 45.5 and indicate a toxicity pass-through during each month. The number of days that measurable toxicity pass-through occurs ranged from 7 days per month to 26 days per month.

TABLE 22. MICROTOX TOXICITY AT PATAPSCO*

1985	IPI[a] INF. Avg. EC_{50}[c]	SWD[b] INF. Avg. EC_{50}	COMBINED INF. Avg. EC_{50}	EFFLUENT Avg. EC_{50}
Jan.	3.0	> 18.2 (27)**	16.5	> 41 (7)**
Feb.	2.7	> 34.5 (12)**	26.6	> 35.3 (17)**
Mar.	3.6	> 33.9 (18)**	18.2	> 25.8 (26)**
Apr.	3.2	> 33.9 (20)**	12.8	> 34.7 (18)**
May	5.8	> 16.4 (27)**	9.4	> 36.0 (16)**
Jun.	8.2	> 13.4 (29)**	9.4	> 40.7 (12)**

[a] IPI, plant influent chiefly from industrial sources.
[b] SWD, plant influent from chiefly domestic-commercial sources.
[c] EC_{50} for a 5-minute exposure time is given as percent effluent.
*Data developed by the Patapsco Wastewater Treatment Plant, Baltimore, Maryland.
**Number of days, the EC_{50} was less than > 45.5 during each month.

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The limited ecosystem bioassay toxicity developed by the EPA on Patapsco plant effluents (Table 23) qualitatively confirmed the variability and pass-through of toxicity indicated by the routine MICROTOX measurements. The results suggest that a desirable statistical link between the pragmatic in-plant monitoring and the expensive Agency ecosystem bioassay may be developed.

Effective toxics control at treatment plants require monitoring tools that can preferably respond in real-time and be used in monitoring approaches to provide warnings of potential toxic impacts or pass-through before the toxics reaches the treatment plant. The specific chemical, (33,34) bioassay toxicity (26,35) and health effects (15) screening tools, many available to the Environmental Protection Agency for the water-quality-based toxics control process, require relatively long measurement times with multi-step procedures. The practical functions of these tools in a TRE are as monitors of the plant's discharge requirements and as linkage to probable receiving water effects and to waste load allocation procedures.

Although limited by their costs, these bioassays could also be used in the development of monitoring approaches for warning of potential toxic plant impacts or pass-throughs and for tracing toxics to their source. However, less expensive and simpler monitoring tools, are more desirable for routine in-plant and in-sewer toxics monitoring.

TABLE 23. EPA BIOASSAY EVALUATION OF THE EFFLUENT AT THE PATAPSCO PLANT

	Fathead Minnow*		Ceriodaphnia**	
Test Date	Survival	Growth	Survival	Reproduction
3/8 - 15/84***	100% Mortality in 100% Effluent	NOEC at 30% Effluent	100% Mortality in 3% Effluent	NOEC at 0.37% Effluent
6/23/84***	45% Mortality in 100% Effluent	—	100% Mortality in 10% Effluent	—
7/13-20/84***	No Mortality at 100%	None up to 6% effluent	100% Mortality at 30% effluent	None up to 6% effluent

*Seven-day Early Life Stage Growth Test using Fathead Minnow.

**Ceriodaphnia Seven-day Life Cycle Toxicity Test.

***Data developed by the Duluth Environmental Research Laboratory, Duluth, Minnesota.

****Data developed by the Environmental Monitoring and Support Laboratory-Newtown Facility, Cincinnati, Ohio.

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In November 1980, the City of Baltimore in anticipation of potential industrial toxics impacts during the start-up and operation of its new activated sludge treatment process at the Patapsco Plant began monitoring its wastewaters for toxicity using the 5-minute MICROTOX (32) analyses. The City ultimately will expand its evaluation to three candidate in-plant monitoring approaches for the TRE study at its Patapsco Wastewater Treatment. These in-plant monitoring tools for indicating the presence of toxicity are the Beckman MICROTOX analyzer with a fluorescent bacterium, respirometry (oxygen uptake) measurements (36,37) on the plant's biomass, and Adenosine Triphosphate (ATP) measurements. These inexpensive monitoring tools have near real-time responses ranging from actual real-time for the TOXIGARD respirometry alternative to about a 1-hour response time for the ATP measurement.

The overall objectives of the planned case history TRE at the Patapsco Plant are given in Table 24. These objectives emphasize use of the pragmatic in-plant monitoring methods and the development of a link between the near real-time measures and the Agency's ecosystem bioassays used in the toxics regulatory process.

TABLE 24. PATAPSCO TOXICITY REDUCTION EVALUATION

Research Objectives:

- Evaluate toxicity reduction across plant using MICROTOX, Respirometry and ATP
- Summarize specific chemical inventory across plant (organics and metals)
- Assess techniques to identify and trace toxicity to sources
- Evaluate link between in-plant monitoring and ecosystem bioassays
- Assess treatability of wastewater for toxics control as related to plant design
- Develop techniques to minimize toxicity pass-through

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SUMMARY

The progress on the toxicity reduction research suggests that the TRE concept, with protocols, has potential to support the wastewater treatment industry's efforts to solve the site specific problems of toxicity discharges by treatment plants. Indeed, the TRE concept with the pragmatic in-plant monitoring tools may be the only affordable approach for managing complex mixtures of toxics, especially in municipal wastewaters.

Key procedures for efficient tracing of the toxicity to its source, identifying the principal components of the toxicity, and demonstrating practical control responses to eliminate excessive toxicity discharges, however, have not yet been sufficiently tested at full-scale treatment plants to confirm the ultimate utility of the concept. Research on approaches to improve the operation of municipal plants for toxics control also has not yet been initiated. The EPA will diligently pursue these remaining research needs to confirm the TRE concept and, thereby, improve the Nation's ability to control toxicity water quality problems from point source discharges.

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